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RELIABILITY, AVAILABILITY AND MAINTAINABILITY ANALYSIS OF THE AQUILA REMOTELY PILOTED VEHICLE SYSTEM

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This report presents an analysis of RAM data obtained during tests conducted at Fort Huachuca, AZ, from July 1977 to November 1977 on the AQUILA Remotely Piloted Vehicle-System Technology Demonstrator. These data were used to estimate the RAM characteristics of the AQUILA RPV system as exhibited during the tests, to provide a RAM data base on an RPV system, to provide a starting point for reliability growth analysis, and to highlight the major failure modes and special RAM problem areas associated with the AQUILA RPV system.

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1. INTRODUCTION

1.1 Purpose

The purpose of this report is to present the RAM analysis and evaluation of the AQUILA RPV system.

1.2 Background

The objective of the AQUILA Remotely Piloted Vehicle System (XMQM-105) program was to develop a system capable of demonstrating the feasibility of using an unmanned aerial vehicle system to conduct real- or near real-time reconnaissance, target acquisition, artillery adjustment and laser designation beyond the FEBA. USACDC TARS-75 and FASTAR studies concluded that the use of manned aircraft to conduct such missions would involve unacceptable losses. The RPV system would complement the current and projected intelligence gathering systems (OV-1, REMBASS, SOTAS, GSR) as well as current and projected combat information systems (GSR, FIREFINDER, FO, FAALS) in the area forward of the FEBA.

During CY72, the Remotely Piloted Aerial Observer Designator System (RPAODS) Program approach was developed, largely at the suggestion of the Director of Defense Research and Engineering and the Office of the Secretary of Defense, to provide a pre-prototype phase with the objective of obtaining realistic specifications for procurement of RPAODS prototypes. The RPAODS program yielded parametric data in such areas as detectability, survivability, target search and acquisition, target tracking and designation, and imagery transmission links.

On 27 September 1974, TRADOC and DARCOM signed a letter of Agreement (LOA) (Reference 1) to jointly develop a Remotely Piloted Vehicle - System Technology Demonstrator (RPV-STD) which would further demonstrate the feasibility of using an RPV to assist the ground commander in performing reconnaissance and target acquisition (R/TA), adjusting artillery fire, and laser designation beyond the FEBA. The LOA identified the unknowns to be resolved by test and experimentation and the specific critical issues to be addressed. Lockheed Missile and Space Corporation (LMSC) was awarded the contract for the AQUILA RPV system on 20 December 1974. As a system technology demonstrator, the major concern was concentrated on developing launch and recovery techniques, preprogrammed flight, and a variety of sensor package capabilities. Since the system was not planned as a fieldable system (non-militarized), human factors engineering, RAM, logistical planning, technical manual preparation, mobility, etc., took a "back seat" in terms of priorities of funds and contractor efforts.

Following fabrication of the system and contractor testing, the system was released to the Army for testing. A Force Development Test and Experimentation (FDT&E) was conducted by the U S Army Field Artillery Board (USAFABD) during the period of 14 July 1977 to 20 October 1977. An Engineering Design Test-Government (EDT-G) was conducted by the U S Army Electronics Proving Ground (USAEPG) during the period of 14 July 1977 to 18 November 1977. Both tests were conducted at Fort Huachuca and were a coordinated effort between USAFABD and USAEPG, incorporating assessment of both tests' objectives at the same site and many times gathering data for both tests during the same flights. Several other tests were conducted after the FDT&E and EDT-G which addressed survivability and an anti-jam data link. Results from all of these tests are used in the AMSAA independent evaluation. For brevity, subsequent references to the USAFABD and USAEPG will be FABD and EPG, respectively.

1.3 System Description

The AQUILA RPV system consisted of five major subsystems: the RPV, the sensor payloads, the ground control station (GCS), the launcher, and the retrieval unit. GFE and other ancillary ground support equipment were also used during testing. The entire system was sufficiently hardened for use outside of laboratory environments to demonstrate the technical and operational properties of immediate interest, but insufficiently militarized or ruggedized for full operational testing. Figure 1.1 shows the RPV system components as setup at the test site.

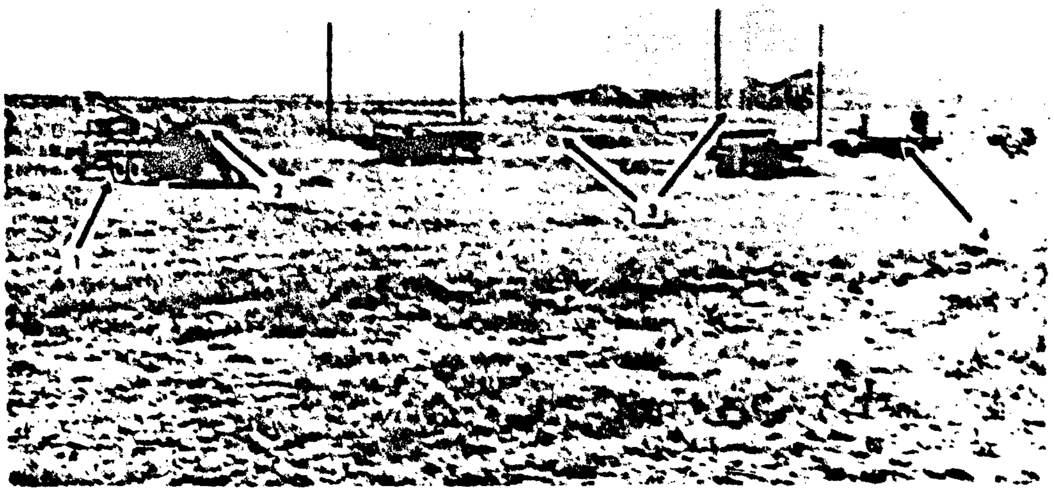
The RPV was an all-wing design, single engine aircraft with a wingspan of 3.6m and a fuselage length of 1.8m. The aircraft contained the flight control package, power supply, receiver, transmitter, engine, and necessary support equipment. The airframe was designed to accept several sensor subsystem configurations. Figure 1.2 shows the RPV.

There were five types of sensors used during the tests. These are designated as Phase I through Phase V.

The Phase I sensor was a gimballed, unstabilized, black and white television (TV) camera which had a remotely controlled zoom lens, focus, and neutral-density filter wheel. An internal iris automatically responded to the light present.

The Phase II sensor was identical to the Phase I sensor except that a 35mm panoramic film camera was added.

The Phase III sensor was a gimballed, stabilized, black and white TV camera which contained a centroid-of-brightness video tracker in addition to the other features of the Phase I sensor.



1. Launcher
2. RPV with Sensor
3. Retrieval System
4. Ground Control Station

Figure 1.1 RPV System Major Components

The Phase IV/V sensor was the stabilized TV sensor with a laser rangefinder and designator incorporated. The TV camera had a fixed focus. The laser was a neodymium-yttruim-aluminum-garnet (Nd-YAG) type operating in the 1064 nanometers region with three pulse rates available: 1, 10 or 20 pulses per second. This was a Class IV laser capable of causing permanent eye damage to unprotected personnel. The two designations for this sensor are used to distinguish between the two major functions: laser rangefinder (Phase IV) and laser designator (Phase V).

The GCS was contained in an S-280 type shelter. It contained two operator consoles: one to control the aircraft systems and perform preflight and inflight status monitoring of the RPV, and a second console to control the sensors on board the aircraft. Additionally, equipment was provided to display and record the imagery from the sensor. The GCS contained a communication/tracking subsystem which consisted of a command and control uplink from the GCS to the RPV to provide aircraft and sensor commands, a telemetry downlink from the RPV to the GCS to carry RPV status data, and a video display and target tracking data link from the RPV

Figure 1.2 Remotely Piloted Vehicle

sensor and target tracking system. Figure 1.3 shows the GCS exterior and Figure 1.4 shows the GCS interior.

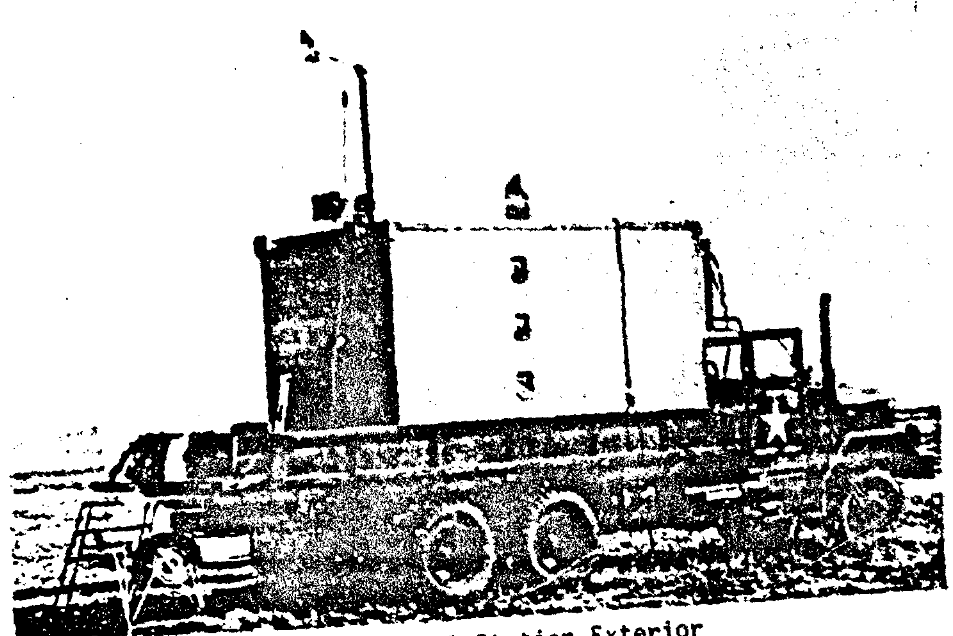


Figure 1.3 Ground Control Station Exterior

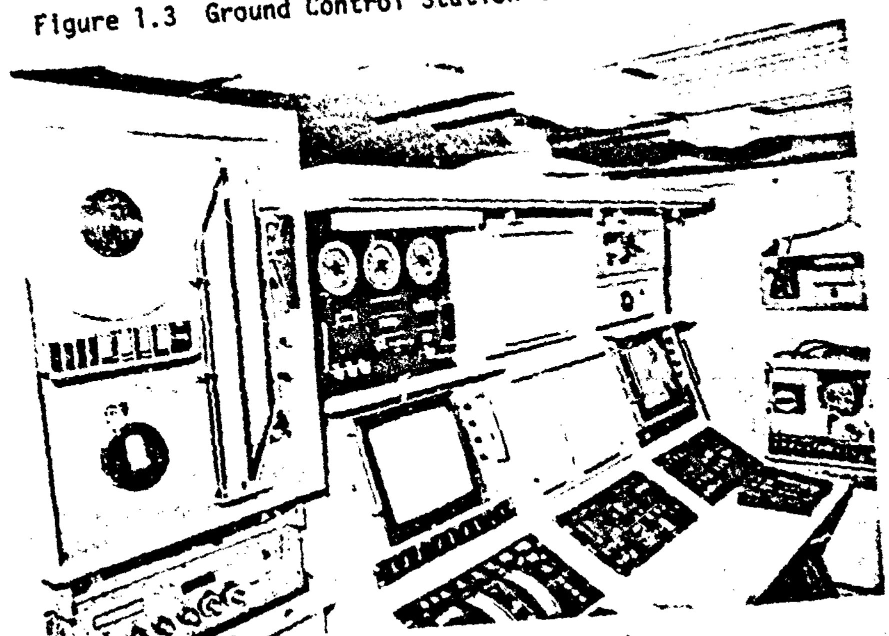


Figure 1.4 Ground Control Station Interior

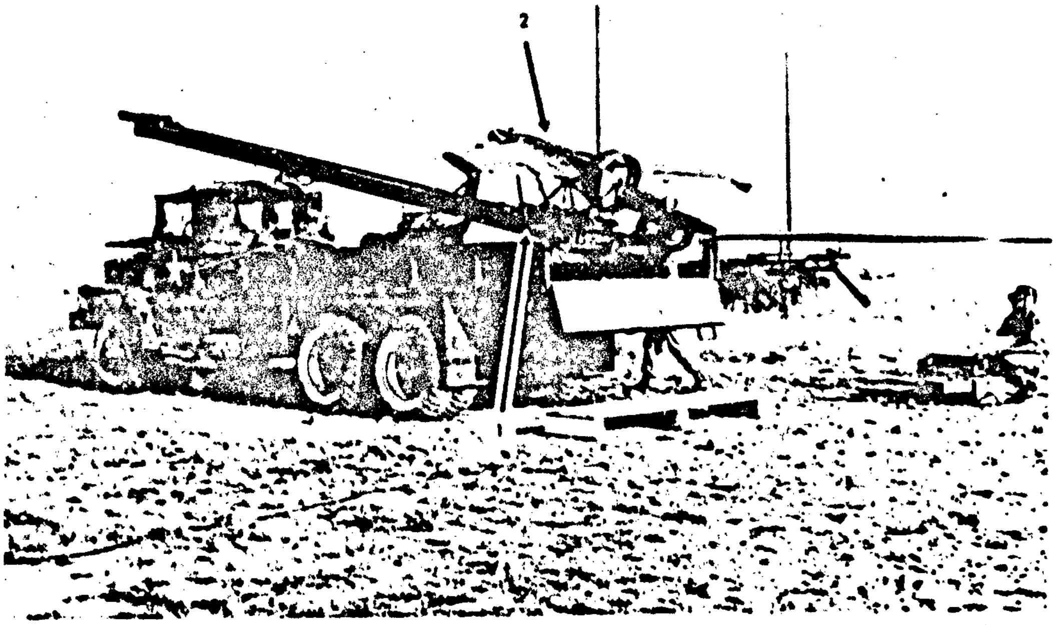


Figure 1.5 Launcher. The pneumatic launcher is indicated by (1) with an RPV (2) being readied for launch.

The launcher subsystem (Figure 1.5) was a truck mounted pneumatically operated catapult. It consisted of two storage cylinders and a power cylinder of aluminum alloy with a pneumatic piston, which was intended to provide a RPV launch speed of about 81.5 Kph with a 6g acceleration.

The retrieval subsystem consisted of two vertical and one horizontal nylon nets supported by two flat-bed trailers. The vertical nets were attached to hydraulic energy absorbers and designed to absorb the forward momentum of the aircraft with minimum damage to protrusions on the aircraft. The RPV was guided into the vertical net by means of a ground mounted TV camera. After the RPV had been captured in the vertical net it fell to rest on the horizontal net. Either vertical net could be erected to provide a bidirectional capability.

The ancillary ground support equipment included two 30 kilowatt (Kw) generators to power the GCS, an assembly/maintenance tent, various test equipment items for checking the mechanical and electrical system status, and handling equipment for the RPV.

1.4 Scope

The AQUILA RPV system did not have the achievement of specific RAM goals as one of its objectives. The data collected during government testing were used to estimate standard RAM parameters for the system as exhibited during the tests and to provide a data base for future evaluations. In addition to these estimates, the major failures and special problem areas are highlighted. Since no RAM data exists on any previous RPV system similar to AQUILA, primarily because there were none, no comparison RAM evaluations can be made. The results of this analysis were used as a starting point for evaluating the reliability growth of the RPV system as it goes through the development cycle. The reliability growth curves present a projected growth rate needed to meet the ROC requirements. By highlighting the special RAM problems encountered during the testing in this analysis, their repetition in any follow-on RPV system should be lessened.

1.5 Data Sources

To date, the Advanced Development Validation Test Phase has been conducted on the AQUILA RPV system. This phase consisted of contractor testing (LMSC), FDT&E, EDT-G, and supporting technology tests in the areas of anti-jam data link and survivability tests. The tests, in addition to addressing the critical issues defined in the LOA, provided data to support the development of the ROC for the Engineering Development RPV program.

The EDT-G was conducted at Fort Huachuca, AZ from July 1977 to November 1977 by EPG personnel. Test objectives included the technical performance of the RPV system, navigation ability, target detection/recognition/identification/location ability, safety, RAM, and human factors. AMSAA wrote the Test Design Plan (TDP) and monitored the tests. The EDT-G test results are presented in the final test report prepared by EPG (Reference 2).

The FDT&E was conducted at Fort Huachuca, AZ from July 1977 to October 1977 by the FABD. Test objectives were similar to those of the EDT-G but stressing mission oriented objectives rather than system limitations. Data was also gathered to address the development of organizational and operational concepts for the follow-on RPV program. Data on personnel selection and training were also collected. The FDT&E test results are documented in a final test report prepared by the FABD (Reference 3).

Although the contractor was required to perform the management functions necessary to analyze the reliability and maintainability characteristics of the system, the contractor did not maintain a comprehensive RAM data collection program. Thus, no contractor RAM data are available for use in this analysis and evaluation. Extensive RAM data were collected during the FDT&E and during the EDT-G. These

data were used to estimate the RAM characteristics of the AQUILA RPV system as demonstrated during government testing. Equipment Performance Reports (EPR) were published by both test teams and provided information on special problems which were not contained on the data collection forms. These EPR's, particularly the set produced by the FDT&E test team, proved invaluable in assessing the qualitative RAM aspects (complexity of the action, ease of fault isolation, repair/replacement) of the RPV system.

1.6 Engineering Development (ED) RAM Requirements.

Throughout this report, the results of AQUILA testing will be compared to the requirements for the ED system set forth in the ROC. This is done to show where the system now stands and how much it has to improve. For quick reference, these requirements are listed below. All reliability figures are based on the mission failure definition.

a. The GCS shall have between a .92 Minimum Acceptable Value (MAV) and .97 Best Operational Capability (BOC) probability of completing 10 hours of operation without a failure. (MAV MTBF value is 120 hours.)

b. The launch unit shall have between .99 (MAV) and .995 (BOC) probability of completing a launch without a failure of the launch unit or the RPV.

c. The RPV system, less sensor, will have between .91 (MAV) and .94 (BOC) probability of completing a 3 hour flight (launch through recovery) without a failure. (MAV MTBF value is 31.8 hours.)

d. Given a successful launch, the RPV system will have a .82 (MAV) and .89 (BOC) probability of completing a 3 hour sortie without imagery failure. (MAV MTBF is 15 hours.)

e. The mean time to repair (MTTR) and maximum time to repair (MAXTTR) of each subsystem shall be no greater than the times indicated for the listed maintenance categories:

	MTTR	MAXTTR
Organizational	.5 hr	1 hr
Field Maintenance (DS/AVIM)	2 hr	4 hr

f. Scheduled maintenance performed during non-operating hours shall require not more than an average of 1 hour per day.

2. RAM ANALYSIS

2.1 RAM Characteristics of the Ground Control Station (GCS)

2.1.1 GCS 002 RAM Data Analysis.

The FDT&E test personnel operated GCS number 002 and were responsible for recording the proper RAM data on it. The EPG test team occasionally shared in the operation of GCS 002 by "piggybacking" a FDT&E test flight. By "piggybacking," we mean that the EPG test team would take over the flight operations after the FDT&E team had completed their flight objectives. This reduced the number or launches and recoveries needed to accomplish test objectives. The EPG test team also used GCS 002 in many of their other test flights. This was due to the fact that their GCS (#001) was not yet operational. All operating times for GCS 002, whether by the FDT&E or the EPG test team, were recorded by the FDT&E data collectors. Assuming a starting time of zero hours when GCS 002 began government testing, there were 288.5 hours of operating time accumulated on GCS 002 during the FDT&E/EDT test. Table 2.1 lists the failures attributed to GCS 002, along with their approximate time of occurrence and the scoring of the failure. Included in this table is one failure which was not scored as a failure to GCS 002 by the scoring conference. This failure was the failure of the ground camera iris control (item 18). Whereas the scoring conference scored it as a failure and charged it to auxiliary support equipment, AMSAA charged it to GCS 002. This decision was made based on the fact that the camera is powered and controlled from the GCS. Several other failures charged to the GCS by the scoring conference could fit into this category, such as items 8 and 15 in Table 2.1. Item 15 was a failure of one of the remote intercom stations located outside the GCS but powered from the GCS and considered necessary for operation of the mission. Item 8 was a failure of the GCS tracking antenna to maintain the proper heading prior to launch. Although presently located on top of the GCS, the Engineering Development (ED) RPV system will probably have a remotely located antenna. In the ED system, any failure of the remote antenna will be charged to the GCS subsystem. Similarly then, the failure of the ground camera is charged to the GCS subsystem since it is essential for the proper control of the RPV during the recovery process. Including this failure in the total number of failures, there were a total of 22 equipment failures and 7.66 mission failures on GCS 002 during the test. This results in an mean-time-between-failure (MTBF) point estimate (equipment) of 13.11 hours and an MTBF point estimate (mission) of 37.66 hours.

Assuming the exponential failure distribution and using the average GCS on-time of 3.2 hours for each mission (including both actual flights and attempted flights), the equipment and mission reliabilities for GCS 002 were estimated. They are .78 and .92, respectively.

TABLE 2.1 FAILURES ON GCS 002 DURING THE FDT&E/EDT KE Equipment Performance Reports (EPR) are FDT&E failures, and KH EPR's are EDT failures. Item 9 resulted in the crash of RPV 022. Item 18 was charged to auxiliary equipment by the scoring conference but is included here (see narrative).

	EPR #	FAILURE SCORE Equipment	Mission	TIME OF OCCURRENCE (HOURS)	DESCRIPTION OF FAILURE
1	KE-13	1	0	27.5	Video tape recorders not recording video
2	KE-33	1	0	54.2	Video tape recorder defective
3	KH-8	1	0	70.0	Erratic data link; tracking on side lobe
4	KE-43	1	0	80.2	Alphanumeric display incorrect
5	KH-10	1	.33	91.5	Camera frame counter
6	KH-11	1	0	98	Camera frame counter
7	KE-54	1	0	108.8	Digital tape recorder circuit breaker tripped
8	KE-58	1	.33	116.2	Tracking antenna slewed off correct heading
9	KE-64	1	1	119.5	Sync lock-up slip in data link; CRASH
10	KE-66	1	0	122.8	Safety intercom plug
11	KE-79	1	0	128.0	In-flight diagnostic panel defective
12	KE-74	0	1	130.2	Software caused RPV to fly erratically
13	KE-78	1	0	139.1	Topaz frequency converter overloading
14	KE-83	1	0	144.9	Focus toggle switch on sensor control panel
15	KE-88	1	0	163.3	Remote intercom unit inoperable
16	KE-90	1	0	170.5	Alphanumeric display temporarily defective
17	KE-100	1	1	184.9	Telemetry receiver panel
18	KE-114	1	0	191.5	Ground camera iris control
19	KE-109	1	0	202.3	Teletypewriter garbling output data
20	KH-33	1	0	205.2	Microphone headset connector
21	KE-120	1	1	219.0	Power control relay
22	KE-127	0	1	234.7	Encoders 15, 16 and 17 out of limits
23	KE-126	1	0	239.1	Teletypewriter ceased to operate
24	KE-123	0	1	239.1	Burst offset calculations incorrect
25	KH-50	1	1	288.5	Flashing ground and lock lights
TOTALS		22	7.66	288.5 operating hours	

For the AQUILA RPV system, maintenance is divided into two basic categories: crew/organizational and contractor field maintenance. These two maintenance categories are essentially analogous to the Aviation Unit Maintenance (AVUM) and Aviation Intermediate Maintenance (AVIM) maintenance categories, respectively, of the three level maintenance system. There were occasions when a component of one of the subsystems would have to be sent back to the contractor facilities for overhaul and/or repair. This could be considered the depot level maintenance category. However, no data exists for this category beyond the fact that it was necessary to return a particular part to the manufacturer for repair. For that reason, this evaluation will emphasize the crew/organizational and the contractor field levels of maintenance.

All maintenance on GCS 002 was performed by the FDT&E team, with the exception of contractor supplied maintenance and three actions by the EPG crew. All scheduled crew/organizational maintenance, excluding site set-up, was performed under the category of premission preventative maintenance (PM). The maintenance parameter estimates resulting from all the maintenance data on GCS 002 are presented in Table 2.2. These estimates include the mean-time-between-maintenance (MTBM, maintenance ratio (MR), mean maintenance time ($\overline{M}$), inherent availability (A_i) and achieved availability (A_a). In columns 2b and 2c are two different sets of values for the unscheduled contractor maintenance parameters. Included in 2c, but not included in 2b, is an unscheduled major GCS technical inspection, overhaul and software change required after the crash of RPV 022 on 19 August 1977. This action was not typical of any of the remaining unscheduled maintenance performed by the contractor. Thus, both these numbers as well as separate availability estimates are presented. Column 3c, which includes this major action, is more representative of the actual availabilities experienced during the testing than is column 3b. Site set-up is not included under column 1a.

The GCS emplacement time was 7.5 hours. This included 2.3 hours for leveling of the GCS/truck with sand bags. A one hour requirement is specified in the RCC for system emplacement time.

2.1.2 GCS 001 RAM Data Analysis.

The EDT test personnel operated GCS 001 and were responsible for collecting the appropriate RAM data on it. GCS 001 had been used in previous contractor testing, but an operating time of zero hours on GCS 001 when turned over to the EPG test team, must be assumed since the contractor did not record operating time. With this assumption, a total of 63.0 hours of operating time was accumulated on GCS 001 by the EPG test team. Table 2.3 lists the failures attributed to GCS 001, along with their approximate time of occurrence and the scoring of the failure. Included in this table is one failure (item 1) which was not scored by the scoring conference but was included in the EDT test report. It is felt that this is a valid failure that was overlooked by the scoring

TABLE 2. 2 MAINTAINABILITY AND AVAILABILITY INDICES FOR GCS 002. NOTE: (c) COLUMNS INCLUDE UNSCHEDULED MAJOR GCS OVERHAUL WHICH IS NOT INCLUDED IN COLUMNS 2(b) or 3(b).

	1 ORGANIZATIONAL/CREW		2 CONTRACTOR			3 ALL MAINTENANCE ACTIONS		
	Scheduled (a)	Unscheduled (b)	Scheduled (a)	Unscheduled (b)	Unscheduled (c)	Scheduled (a)	Unscheduled (b)	Unscheduled (c)
Avg Maint Time Clhr	.61	.49	2.5	1.63	5.5	.71	1.04	3.00
Mnhr	1.44	.71	5.7	3.04	12.7	1.67	1.83	6.71
MTBM (hrs)	5.44	19.23	95.2	20.61	19.2	5.16	9.95	9.62
MR	.30 mnhr/op		.21 mnhr/op hr		.72*	.51 mnhr/op hr		1.02*mnhr/op hr
$\overline{M}$	.58 hr		1.79 hr		5.02* hr	.82 hr		1.51*hr
A_i	.97					.91		.76*
A_a	.88					.805		.69*

*includes scheduled and unscheduled actions.

conference. This failure is also included in this analysis. With a total of 63 operating hours, 7 equipment failures, and 2 mission failures recorded on GCS 001, the equipment and mission mean-time-between-failure point estimates are 9.0 and 31.5 hours, respectively. Assuming an exponential failure distribution and using the average GCS on-time of 3.2 hours for each mission (including both scrubbed and actual flights), point estimates are .70 for the equipment reliability and .90 for the mission reliability. The average GCS on-time as determined from the EDT&E data was used because EDT data listing the operating hours for each instance that GCS 001 was powered for a mission, were not available.

The EPG RAM data collectors did not record maintenance data on contractor maintenance actions; therefore, only organizational/crew level maintenance data are used in the analysis. A summary of the maintenance parameters resulting from this maintenance data on GCS 001 is presented in Table 2.4.

TABLE 2.3 FAILURES RECORDED ON GCS 001 DURING THE EDT

	EPR #	Failure Score Equipment	Failure Score Mission	Time of Occurrence (Hours)	Description of Failure
1	KH-49	1	0	10.0	Waypoint guidance panel
2	KH-54	1	1	16.5	Integrated circuit on electronics interface unit
3	KH-56	1	0	16.8	Video recorder inoperative
4	KH-68	1	0	40.7	Line fuse in pilot's monitor
5	KH-69	1	0	43.8	LED on waypoint command status panel
6	KH-71	1	0	54.1	Ground lock light burned out
7	KH-72	1	1	63.0	Ground and lock lights flickering; aborted flight
	TOTALS	7	2	63.0 operating hours	

TABLE 2.4 MAINTAINABILITY AND AVAILABILITY INDICES FOR GCS 001

	Average Maintenance Time Clock Hour	Average Maintenance Time Man Hours	MTBM	MR	$\bar{M}$	Ai	Aa
Scheduled	.50	1.37	5.25 hr				
Unscheduled	.66	.87	9.00 hr				
Combined	.56	1.19	3.32 hr	.36	.56 hr	.93	.86

2.1.3 Analysis of Aggregated GCS RAM Data

By combining the information in Tables 2.1 and 2.3, there are a total of 29 equipment failures, 9.66 mission failures, and 351.5 operating hours accumulated on the two ground control stations used during government testing. With these values, the following MTBF's and reliabilities for the GCS subsystem were estimated:

Equipment MTBF	12.12 hours
Equipment Reliability (t = 3.2 hours)	.76
Mission MTBF	36.39 hours
Mission Reliability (t = ,.2 hours)	.92

The maintainability and availability indices for the GCS subsystem are presented in Table 2.5. Again, separate values are given for the unscheduled maintenance parameters for contractor and overall maintenance due to the unscheduled major GCS overhaul after the crash of RPV 022. (Section 2.1.1.)

There were few mai tenance difficulties associated with the GCS subsystem; most difficult :s were in the area of human factors. Some of the problems experienced during GCS maintenance were:

1) Repair/replacement parts were inadequate. Spare light bulbs and fuses for the GCS were not provided. Cannibalization from one GCS to the other was sometimes required to effect repairs.

2) During emplacement of the GCS, extreme difficulty was experienced while attempting to level the 2 1/2 ton cargo truck containing the GCS to prescribed tolerances.

3) Maintenance personnel encountered extreme difficulty in the repair and maintenance of the #2 topaz frequency changer. The two units, weighing more than one hundred pounds each, require more than one person to handle. The #2 unit, located beneath the main control console, cannot be reached by more than one person at a time during installation or repair. One member of the player platoon sustained a back injury when attempting to remove the #2 unit. This injury was caused by a lack of hand holds, the weight and the poor location of the unit.

The test results showed a mission reliability of .92 based on a 3.2 hour mission. The requirement for the GCS subsystem at IOC is .92 (MTBF = 120 hours); however, this is based on a 10 hour day of continuous operation. Using a 10 hour base and the MTBF of 36.39 hours exhibited during the FDT&E/EDT, a mission reliability of .76 is determined by using the exponential failure distribution. Thus, engineering improvements and military hardening will be necessary on the ED systems GCS in order to meet this requirement.

TABLE 2.5 MAINTAINABILITY AND AVAILABILITY INDICES FOR THE GCS SUBSYSTEM. NOTE: COLUMNS 2(c) AND 3(c) INCLUDE UNSCHEDULED MAJOR GCS OVERHAUL; NOT INCLUDED IN 2(b) OR 3(b).

		Organizational/Crew (AVUM)		Contractor (AVIM)			All Maintenance Actions		
		Sched. (a)	Unsched. (b)	Sched. (a)	Unsched. (b)	Unsched. (c)	Sched. (a)	Unsched. (b)	Unsched. (c)
Avg Maint Time	Clk hr	.59	.54	2.50	1.63	5.47	.67	.96	2.56
	Man hr	1.43	.76	5.70	3.04	12.70	1.62	1.65	5.60
MTBM		5.41 hr	15.98 hr	17.17 hr	25.11 hr	23.43hr	5.17 hr	9.76 hr	9.50 hr
MR		.31 man hr/op hr		.17 man hr/op hr		.59*	.48 man hr/op hr		.90* man hr/op hr
$\overline{M}$		.58 hr		1.79 hr		5.02*hr	.77 hr		1.34*hr
Ai							.91		.79*
Aa							.81		.71*

*includes scheduled and unscheduled actions.

2.2 RAM Characteristics of the RPV Subsystem

2.2.1 Analysis of FDT&E RAM Data on the RPV Subsystem

The FDT&E test personnel operated RPV's 014, 016, 018, 020 and 022. The EPG test personnel also operated RPV's 014 and 018 after the FDT&E was terminated. The operating time on these two RPV's is not included here but is discussed separately in the EPG analysis section, 2.2.2, and collectively in the aggregated data analysis section, 2.2.3.

The RPV's experienced numerous failures during the conduct of the test. Most of these failures were not catastrophic. Table 2.6 lists the failures scored against the RPV subsystem during the FDT&E. The failure recorded on EPR KE-128 (28 September) was the only failure of the RPV subsystem which resulted in a crash during the FDT&E. This failure is suspected (but not confirmed) to be a quality control problem where a counterweight on the engine came off in flight causing the engine to quit. Two other RPV's crashed during the conduct of the FDT&E, neither of which was caused by a failure of the RPV subsystem. The first crash on 19 August 1977 was caused by a sinc-lock slip in the data link and is listed as a GCS failure (see Table 2.1, item 9). The second crash on 1 September was due to a human error prior to launch. A launch crewman left a small wrench on the wing which went through the propeller at launch, destroying it. Several other failures listed in Table 2.6 could have resulted in a catastrophic failure had they not been discovered and corrected during the numerous pre-flight checks and inspections. These proved to be very valuable in helping to insure a successful flight and completion of the test mission objectives.

Of the 32 RPV equipment failures (excluding quality control induced problems), nine were associated with the engine failing to either start, stop or maintain the proper RPM or temperature. Engine RPM problems were experienced often during the countdown to launch and were not always reported as failures. The engine had difficulty obtaining the desired launch and idle RPM speeds during the launch countdown. This sometimes resulted in a delayed or scrubbed mission. The problems were usually alleviated by cleaning or changing the spark plug, by adjusting the carburetor, or by allowing extra engine warm up time. In general, the engine was underpowered for some of the missions it was required to perform, especially for the Fort Huachuca altitude. This engine will not be used in the RPV Engineering Development Program; a new engine is currently being developed.

Another recurring problem was cracking of the copper waveguide on the video transmitter. It was suggested by the RAM data collectors that a flexible type coaxial cable may be more appropriate and may help prevent this type of failure from recurring. Several other repeated equipment failures were exhibited during the FDT&E. Some of these were: payload protector (3 failures), flight control electronics package (2 failures), servo actuator (2 failures) and magnetometer (2 failures).

TABLE 2.6 FAILURES ASSOCIATED WITH THE RPV'S WHICH WERE USED DURING THE FDT&E. QUALITY CONTROL FAILURES ARE INDICATED BY AN ASTERISK (*) AND ARE TOTALED SEPARATELY.

Serial #	EPR #	Failure Score Eq.	Failure Score Mis.	RPV Age (Hours) Flt.	RPV Age (Hours) All	Total to Date (Hours) Flt.	Total to Date (Hours) All	Description of Failure
014	KE-4	1	1	0	0	0	0	Electronics Control Package
016	KE-6	1	0	0	0	0	0	Engine failed to start
016	KE-9	1	1	0	1.7	0	1.7	Attenuated signal strength
016	KE-9	1	1	0	1.7	0	1.7	Transmitter cables reversed
016	KE-10	1	0	0	1.7	0	1.7	Payload protector latch springs
016	KE-15	1	0	.3	3.9	.3	3.9	Alternator drive shaft
014	KE-18	1	0	0	0	.3	3.9	RF connector to transmitter
014	KE-19	1	0	0	1.5	.3	5.4	Flight control electronics package
014	KE-24	1	1	2.8	6.0	3.1	8.3	Carburetor cable assembly
020	KE-25	1*	0	0	1.6	4.6	11.9	Accelerator mount bracket
014	KE-26	1	0	2.8	6.0	4.6	12.1	Payload protector
014	KE-26	1	0	2.8	6.0	4.6	12.1	Engine failed to stop on command
020	KE-30	1*	0	0	1.8	6.9	17.1	Skeg for launcher mating too large
020	KE-31	1	1	0	1.8	6.9	17.1	Two-axis rate gyro
016	KE-32	1	0	.3	3.9	6.9	17.1	Payload protector right knee support
016	KE-36	1	0	2.8	6.8	10.2	21.0	Bulkhead screw
016	KE-37	1	1	2.8	7.8	10.2	21.0	Engine RPM and temperature improper for launch
020	KE-41	1	1	.8	2.8	12.7	24.3	Engine throttle problems
020	KE-45	1*	0	.8	2.8	12.7	24.3	Weight and balance problems
016	KE-48	1	0	7.2	13.9	15.5	30.9	Copper waveguide on video transmitter
016	KE-51	1	1	11.4	20.0	19.7	37.0	Engine RPM terminated launch attempt
022	KE-53	1*	0	0	0	19.7	37.0	Bolt holes for wing attachment
020	KE-57	1	1	4.4	11.5	22.4	42.4	Servo actuator shorted
016	KE-59	1	0	13.2	22.7	24.2	45.1	Engine wouldn't start; spark plug cleaned
018	KE-70	1*	0	0	0	27.7	50.0	Safety wire on air speed tubing
018	KE-70	1*	0	0	0	27.7	50.0	Crimped altitude transducer tube
018	KE-70	1*	0	0	0	27.7	50.0	Wing attachment screws
018	KE-70	1*	0	0	0	27.7	50.0	Weight and balance attachments
018	KE-71	1*	0	0	0	27.7	52.5	Cable harness to sensor

TABLE 2.6 (Continued) FAILURES ASSOCIATED WITH THE RPV'S WHICH WERE USED DURING THE FDT&E. QUALITY CONTROL FAILURES ARE INDICATED BY AN ASTERISK (*) AND ARE TOTALED SEPARATELY.

Serial #	EPR #	Failure Score Eq.	Failure Score Mis.	RPV Age (Hours) Flt.	RPV Age (Hours) All	Total to Date (Hours) Flt.	Total to Date (Hours) All	Description of Failure
018	KE-71	1*	0	0	0	27.7	52.5	Grounding terminal too small
018	KE-72	1*	0	0	0	27.7	52.5	Battery leads missing
020	KE-75	1	1	4.4	14.7	28.2	54.5	Engine died 3 times during countdown
016	KE-80	1	0	18.2	29.0	30.5	57.2	Fuel low indicator defective
018	KE-85	1	1	0	1.0	34.2	63.0	Engine problems during countdown
018	KE-96	1	0	.5	1.9	38.6	68.4	RPV magnetometer
018	KE-99	1	1	.5	2.4	38.6	68.9	Voltage regulator
018	KE-103	1	1	2.6	5.1	40.7	71.6	RPV magnetometer
020	KE-108	1	0	12.0	23.5	47.4	79.5	Copper waveguide to video transmitter
018	KE-111	1	0	9.3	13.0	48.9	81.3	Copper waveguide to video transmitter
020	KE-124	1	0	18.6	31.6	58.4	93.0	Engine spark plug caused rough running
020	KE-125	1	0	18.6	31.6	58.4	93.0	Copper waveguide to video transmitter
020	KE-128	1	1	20.7	34.3	62.5	98.1	Engine counterweight thrown off in flight/crash
018	KE-129	1*	1*	18.5	24.7	65.3	102.0	Improper solder of connector pin on magnetometer
018	KE-132	1	0	25.1	33.5	71.9	110.8	Left servo actuator jamming
014	KE-134	1*	0	6.6	11.2	71.9	110.8	Sensor mounts not installed after overhaul
TOTALS		32	14			78.4	118.3	hours
		45	15 including quality control induced failures					

These and many of the other types of failures listed in Table 2.6 could be eliminated or the frequency reduced by proper design and manufacturing techniques.

Table 2.7 lists the MTBF and reliability estimates for each RPV platform and for the total RPV subsystem. Values both including and excluding the quality control failures are given. These values would not be acceptable in the ED system. It is recognized that this system was not designed for reliability and that many improvements will be necessary. Reliability is estimated assuming an exponential failure distribution with an average mission on-time of 1.88 hours. (The FABD used 1.7 hours in their analysis.) This was found by adding the average of 1.7 flight hours (46 flights) and the average engine run time on the launcher of .18 hours (51 entries, including both flights and scrubbed missions). Mean time between failure (MTBF) is based on the total engine running time, not flight hours which was used in the FABD analysis. (See Reference A.) Note that engine run time differs slightly from all time (listed in Table 2.6) in that all time also includes electrical power on time while on launcher prior to engine start.

TABLE 2.7 RELIABILITY PARAMETERS FOR THE RPV'S USED BY THE FABD DURING THE FDT&E. VALUES WHICH INCLUDE THE QUALITY CONTROL FAILURES ARE GIVEN IN PARENTHESES.

RPV	OPERATING TIME, HRS FLT.	ENG.	FAILURES EQUIPMENT	MISSION	MTBF, HOURS (ENGINE ON TIME) EQUIPMENT	MISSION	RELIABILITY (t = 1.88 HRS) EQUIPMENT	MISSION
014	6.6	7.8	6(7)	2	1.3 (1.11)	3.9	.23(.18)	.62
*016	18.2	24.4	12	4	2.03	6.1	.40	.73
018	31.6	34.5	6(14)	3(4)	5.75(2.46)	11.5(8.62)	.72(.47)	.85(.80)
*020	20.7	23.2	8(11)	5	2.9(2.11)	4.64	.52(.41)	.67
*022	1.3	1.8	0(1)	0	(1.8)	—	(.35)	—
TOTAL	78.4	91.7	32(45)	14(15)	3.18(2.26)	7.27(6.79)	.55(.43)	.77(.76)

*Crashed RPV's

According to the FDT&E RAM data collectors/evaluators, the most difficult subsystem to maintain was the RPV subsystem. The number of clockhours and man-hours, both corrective and preventative, required on the RPV per flight hour may be considered excessive (see Table 2.9) when compared to the ED system requirements. Poor equipment design and characteristics, lack of sufficient tools, and inadequate technical manuals are the primary reasons for the difficulties experienced during maintenance. Another reason for the inordinate amount of RPV maintenance was the poor quality control exhibited by the contractor. Twenty-nine percent of the equipment failures charged to the RPV subsystem in FDT&E were due to a lack of proper quality control. RPV's were received from the contractor facility with such things as missing sensor mounts, missing battery and terminal leads, no weight and ballast fixtures,

TABLE 2.8 FDT&E MAINTENANCE ACTIONS ON THE RPV SUBSYSTEM

	Level	Maintenance Action	Number of Actions	Total Hours Cl-Hrs	Total Hours Man-Hrs	Mean Cl-Hrs	Mean Man-Hrs	Std. Dev. Cl-Hrs	Std. Dev. Man-Hrs
Scheduled	Crew/Org.	Post flight w/SCT	25	50.1	78.6	2.0	3.1	.61	1.43
		Pre-flight	7	12.5	23.0	1.8	3.3	1.40	2.78
		Post/Pre-flight	12	28.7	59.2	2.4	4.9	.76	2.55
		Button-up inspection	41	44.5	89.5	1.1	2.2	.22	.64
		Weight and Balance	6	12.1	31.6	2.0	5.3	.71	2.13
		Wt. and Bal. w/sensor installation	2	11.3	25.6	5.6	12.8	1.20	4.53
		Sensor installation	6	8.6	9.1	1.4	1.5	.64	.65
		Other scheduled	7	4.0	5.1	.6	7.3	.68	.75
		TOTAL (Crew/Organizational)	106	171.8	321.7	1.6	3.0	.98	2.34
	Contractor	General scheduled	5	13.0	32.8	2.6	6.6	2.44	5.79
	Both	Total scheduled	111	184.8	354.5	1.7	3.2	1.09	2.65
Unsch.	Crew/Org.	General unscheduled	41	41.6	62.0	1.0	1.5	.85	1.77
	Contractor	General unscheduled	21	73.1	154.4	3.5	7.4	2.44	6.47
	Both	Total unscheduled	62	114.7	216.4	1.8	3.5	1.95	4.85
	Crew/Org.	All maintenance	147	213.4	383.7	1.4	2.6	.98	2.30
	Contractor	All maintenance	26	86.1	187.2	3.3	7.2	2.40	6.25
	Both	All maintenance	173	299.5	570.9	1.7	3.3	1.45	3.59

accelerometer bracket too large, sensor wiring harness bundled improperly, and improperly positioned wing attachment bolt holes. Such poor quality control should not be allowed to continue with the ED system.

Table 2.8 lists the types of maintenance performed on the RPV subsystem. Some items are listed as specific actions while others are under general headings due to the large numbers of actions on this subsystem. Aircraft assembly time is not included in these figures. This accounts for the differences between these figures and those presented in the FDT&E report. For the most part, unscheduled maintenance corresponds with the failures listed in Table 2.6. Some examples of other types of unscheduled maintenance are: recovery damage repairs, component checks, and field engineering fixes.

RPV assembly time was excluded from the computations because this series of actions is not typical of the average scheduled maintenance times as listed in Table 2.8. Assembly was performed on only three of the aircraft (RPV 018, 020 and 022) since two (RPV 014 and 016) were received in an assembled configuration from the contractor. Assembly times varied widely on each airframe due to operator inexperience and quality control problems peculiar to each of the airframes. The weight and balance times and sensor installation times during assembly of the three airframes were included in the averages presented in Table 2.8. The remainder of the assembly time and checkout time for the three airframes is summarized below (the figure in parenthesis includes the weight and balance and sensor installation times):

RPV 018: 12.9 (16.6) clock hours, 27.2 (32.9) man-hours
RPV 020: 10.7 (13.2) clock hours, 19.2 (27.2) man-hours
RPV 022: 25 (29) clock hours, 33 (41) man-hours

All these times should be reduced in the ED RPV system.

Table 2.9 summarizes the maintainability and availability indices for the RPV subsystem. Mean-time-between-maintenance (MTBM) and the availabilities are based on the engine on-time of 91.7 hours. Maintenance ratio (MR) is based on the total flight time of 78.4 hours.

TABLE 2.9 MAINTAINABILITY AND AVAILABILITY INDICES FOR THE RPV SUSSYSTEM DURING FDT&E

	Organ./Crew(AVUM)		Contractor		All Maintenance Actions	
	Sch.	Unsched.	Sch.	Unsched.	Sch.	Unsched.
Avg Cl-Hrs	1.6	1.0	2.6	3.5	1.7	3.2
Avg Man-Hrs	3.0	1.5	6.6	7.4	1.8	3.5
MTBM	.86 hr	2.2 hr	18.3 hr	4.4 hr	.83	.53 1.48 hr
MR	4.89 man-hr/flt hr		2.39 man-hr/flt hr		7.28 man-hr/flt hr	
$\overline{M}$	1.43 hours		3.33 hours		2.22 hours	
A_i					.44	
A_a					.23	

2.2.2 Analysis of EDT RAM Data on the RPV Subsystem

The EDT test personnel operated RPV's 014, 017, 018, 019, 021 and 023. RPV 014 and 018 had been operated during the FDT&E and were turned over to the EDT at the termination of the FDT&E.

Numerous failures, most of which were not catastrophic, were experienced on the RPV subsystems during the EDT. Table 2.10 lists the failures scored against the RPV subsystem during the EDT. All three RPV crashes during the EDT were due to failures on the RPV. On 26 September 1977, RPV 021 crashed after the engine quit in flight. The engine began having RPM problems after a manually commanded altitude reduction and died when trying to increase the throttle. On 14 October 1977, RPV 017 crashed after a crankshaft counterweight broke free and made a hole in the engine crankcase. On 20 October 1977, RPV 023 crashed due to a failure of one of the integrated circuits on altitude control card A4. A constant RPM command of 4000 RPM resulted and there was no response to input commands.

The most recurring failure during the EDT was failures of the elevon servo actuator. There were seven recorded equipment failures of this type. This type of failure occurred more often during EDT than during FDT&E (2 failures). Some of the failure modes associated with the elevon servo actuator were stripped gears, overheating, shorting or open circuiting, jamming and freezing in position, and being out of tolerance. Spares were insufficient. A better designed actuator will be necessary in the ED program to reduce the number of failures on this piece of equipment.

Engine failures also presented problems during the EDT, as they did during the FDT&E. Four incidents were recorded, one of which caused a crash. These were all associated with RPM problems and engine dying when throttle changes were commanded. Four other failures could also be considered to be associated with the engine. These were failures of the throttle cable (KH-64), crankshaft counterweight (KH-48) which caused a crash, a broken magneto wire (KH-53) which kept the engine from being killed after recovery, and a sheared throttle linkage mount bolt (KH-58). As stated in section 2.2.1, this engine will not be used in the ED system; a new engine is being developed. These types of failures should be minimized on the new engine, especially the RPM problems.

There were three failures of the rate gyro and two on the A4 card in the Flight Control Electronics Package (FCEP). The failure mode most often associated with the rate gyro was erratic behavior causing excessive drift. Failures in the FCEP were due to a failed IC on the A4 card.

Table 2.11 lists the MTBF and reliability estimates for each RPV platform and for the total RPV subsystem as exhibited during the EDT.

TABLE 2.10 FAILURES ASSOCIATED WITH THE RPV'S WHICH WERE USED DURING THE EDT. QUALITY CONTROL FAILURES ARE INDICATED BY AN ASTERISK (*) AND ARE TOTALED SEPARATELY.

Serial #	EPR #	Failure Score Eq.	Failure Score Mis.	RPV Flight time at time of failure, hrs	Total hrs at end of test Flt.	Total hrs at end of test All	Description of Failure
014	KH-61	1	0	1.2			Elevon servo actuator
	KH-64	1	1	1.2	9.6	11.5	Throttle cable
017	KH-21	1	0	2.5			Buffer assembly
	KH-31	1	0	3.8			Elevon servo actuator
	KH-46	1	0	6.6			Elevon servo actuator
	KH-48	1	1	9.0	9.0	11.3	Crankshaft counterweight (CRASH)
018	KH-53	1	0	1.3			Magneto wire
	KH-60	1	0	3.1			Elevcn servo actuator
	KH-70	1	0	8.2	12.3	14.4	A4 card in FCEP
019	KH-16	1	1	1.3			Engine problems
	KH-26	1	1	2.8			Elevon servo actuator
	KH-58	1	0	4.0			Throttle linkage mount bolt
	KH-62	1	0	4.4			Elevon servo actuator
	KH-63	1	0	4.4			Airspeed transducer
	KH-65	1	1	5.1	5.1	7.5	Engine RPM problems
021	KH-36	1*	0	1.2			Pilot tube repositioned
	KH-37	1	0	1.2			Rate gyro
	KH-38	1	0	1.7			Spline key on prop shaft
	KH-41	1	1	1.9	1.9	2.3	Engine RPM problems (CRASH)
023	KH-20	1	1	1.7			Lost link due to transmitter
	KH-23	1	0	1.7			Altitude rate gyro
	KH-24	1	1	1.7			Battery
	KH-25	1	0	2.6			Elevon servo actuator
	KH-32	1	1	3.9			Engine RPM problems
	KH-34	1	0	3.9			Alternator flex shaft adapter
	KH-42	1	0	3.9			Propeller
	KH-43	1	0	6.6			Rate gyro
	KH-49	1	0	7.4	7.4	9.1	Altitude control card A4 (CRASH)
TOTALS		27	10		45.3	56.1 hours	
		28	10 including quality control induced failures				

TABLE 2.11 RELIABILITY PARAMETERS FOR THE RPV'S USED BY EPG DURING THE EDT. VALUES WHICH INCLUDE THE QUALITY CONTROL FAILURES ARE GIVEN IN PARENTHESES. RPV'S 014 AND 018 WERE ALSO USED DURING THE FDT&E; OPERATING TIME GIVEN IS FOR EDT USE ONLY.

RPV	Operating Time, hr		Failures		MTBF, hr		Reliability (t = 1.88 hours)	
	Flight	Engine	Equipment	Mission	Equipment	Mission	Equipment	Mission
014	9.6	11.5	2	1	5.75	11.50	.72	.85
*017	9.0	11.3	4	1	2.82	11.30	.51	.85
018	12.3	14.4	3	0	4.80	—	.68	—
019	5.1	7.5	6	3	1.25	2.50	.22	.47
*021	1.9	2.3	3(4)	1	.77(.57)	2.30	.09(.04)	.44
*023	7.4	9.1	9	4	1.01	2.27	.16	.44
TOTAL	45.3	56.1	27(28)	10	2.07(2.00)	5.61	.40(.39)	.71

*Crashed RPV's

Estimates both including and excluding the quality control failure are given. These estimates were made by assuming an exponential failure distribution. For consistency in this analysis, the average mission time of 1.83 hours found during the FDT&E is used instead of the 1.6 hours used in the EDT analysis performed by EPG. MTBF is based on the total engine running time, not on flight time which was used in the EPG analysis (see Reference 2). These two differences account for the slight differences between this analysis and the EPG analysis.

From the low reliabilities shown in Table 2.11, it is apparent that many improvements will be necessary to insure that the RPV subsystem meets the requirements specified for the ED system. The reliability figures in Table 2.11 are slightly lower than those found during the FDT&E (see Table 2.6).

As during the FDT&E, maintenance on the RPV was also a problem during the EDT. Two major maintenance problems during EDT were most prominent. The first was that there was insufficient space in the RPV for placing the hands when the elevon servo actuator and the sensor package had to be removed. It was recommended in the EDT test report that handles or lifting brackets be placed on the sensor package. The second problem mentioned was that it was easy to place the propeller on backwards. Markings were insufficient for determining the proper orientation. Proper markings or designing so that the propeller only fits one way would alleviate this problem. In general, maintenance on the RPV was difficult and time consuming. It was remarked that the only easy part to replace was the rate gyro.

Table 2.12 summarizes the maintainability and availability indices for the RPV subsystem during EDT. Mean-time-between-maintenance (MTBF) and availability estimates are based on the total engine on-time of 56.1 hours. (EPG based their calculations on flight time.) Maintenance ratio (MR) is based on the total flight time of 45.3 hours.

TABLE 2.12 MAINTAINABILITY AND AVAILABILITY INDICES FOR THE RPV SUBSYSTEM DURING EDT

	Organ./Crew		Contractor		All Maintenance	
	Sched.	Unsched.	Sched.	Unsched.	Sched.	Unsched.
Avg Cl-Hrs	1.72	1.02			1.72	1.02
Avg Man-Hrs	4.21	1.49	Not Recorded		4.21	1.49
MTBM	.78 hr	1.87 hr			.78	.55 | 1.87 hr
MR	7.68 man-hr/flt hr				7.68 man-hr/flt hr	
$\bar{M}$	1.50 hours				1.50 hours	
A_i					.65	
A_a					.27	

2.2.3 Analysis of Aggregated RPV RAM Data

To determine the overall RAM indices of the RPV subsystem during government testing, the data presented in Sections 2.2.1 and 2.2.2 were combined. Table 2.13 summarizes the number of failures, operating time, MTBF and reliability experienced by the RPV subsystem. MTBF is based on the engine-on time and all reliability estimates are based on an average mission duration of 1.88 hours.

These values of MTBF and reliability would not meet the ED system requirements. Many improvements would be necessary on the AQUILA RPV subsystem to bring it up to the requirements specified in the ROC. The failures which occurred most frequently are reiterated below:

Engine failures (RPM, throttle, carburetor, magneto, crankshaft problems): 21 equipment, 13 mission
Elevon servo actuator failures: 9 equipment, 2 mission
FCEP failures: 4 equipment, 2 mission
Rate gyro failures: 4 equipment, 1 mission
Copper waveguide failures: 4 equipment
Payload protector failures: 3 equipment

As stated in the previous two sections, maintenance on the RPV subsystem was difficult and time consuming. Poor equipment design and characteristics, poor layout, poor quality control, lack of sufficient tools, and inadequate technical manuals are the reasons given most often for the difficulties experienced in RPV maintenance. Table 2.14 summarizes the maintainability and availability indices for the overall RPV subsystem as exhibited during government testing. MTBM and the availabilities are based on the total engine on-time of 147.8 hours. MR is based on the total flight time of 123.7 hours. In view of the ED system requirements, an excessive amount of time and man-hours was spent on all maintenance actions. Many man-hours were spent on RPV maintenance in order to achieve 1 flight hour (i.e., MR = 7.4 man-hours per flight hour).

2.3 RAM Characteristics of the Sensor Subsystem

2.3.1 Analysis of FDT&E RAM Data on the Sensor Subsystem

The FDT&E test personnel operated Phases I, III, IV and V sensor packages. A Sony camera was used occasionally to check out a new RPV platform on its first flight; this camera is not part of the evaluation. The FDT&E test team was only interested in testing phases III, IV and V. Thus, the single failure for the Phase I sensor was not included in their reliability analysis. However, Phase I maintenance times and operating times were included, thus giving an incorrect representation of the RAM parameters for the FDT&E test. For consistency, this analysis will include all FDT&E Phase I sensor RAM data in this section and in the aggregation section.

TABLE 2.13 RELIABILITY PARAMETERS FOR THE RPV'S USED DURING GOVERNMENT TESTING. VALUES WHICH INCLUDE THE QUALITY CONTROL FAILURES ARE GIVEN IN PARENTHESES.

RPV	Operating Time (Hours) Flight	Operating Time (Hours) Engine	Failures Equipment	Failures Mission	MTBF (Hours) Equipment	MTBF (Hours) Mission	Reliability Equipment	Reliability Mission
014	16.2	19.3	8(9)	3	2.4(2.1)	6.4	.46(.42)	.75
*016	18.2	24.4	12	4	2.0	6.1	.40	.73
*017	9.0	11.3	4	1	2.8	11.3	.51	.85
018	43.9	48.9	9(17)	3(4)	5.4(2.9)	16.3(12.2)	.71(.52)	.89(.86)
019	5.1	7.5	6	3	1.2	2.5	.22	.47
*020	20.7	23.2	8(11)	5	2.9(2.1)	4.6	.52(.41)	.66
*021	1.9	2.3	3(4)	1	.8(.6)	2.3	.09(.04)	.44
*022	1.3	1.8	0(1)	0	(1.8)	—	(.35)	—
*023	7.4	9.1	9	4	1.0	2.3	.15	.44
TOTAL	123.7	147.8	59(73)	24(25)	2.5(2.0)	6.2(5.9)	.47(.39)	.74(.73)

*Crashed RPV's

TABLE 2.14 MAINTAINABILITY AND AVAILABILITY INDICES FOR THE RPV SUBSYSTEM DURING GOVERNMENT TESTING

	Organizational/Crew		Contractor		All Maintenance	
	Sched.	Unsched.	Sched.	Unsched.	Sched.	Unsched.
Avg Clk-hrs	1.7	1.0	2.6	3.5	1.7	1.6
Avg Man-hrs	3.5	1.5	6.6	7.4	3.6	2.2
MTBM	.8 hr	2.1 hr	29.5 hr	7.0 hr	.8 .5	1.6 hr
MR	5.9 man-hr/ flt hr		1.5 man-hr/ flt hr		7.4 man-hr/ flt hr	
$\overline{M}$	1.5 hr		3.3 hr		1.7 hr	
A_i					.50	
A_a					.25	

Table 2.15 lists the failures scored against the sensor subsystem during the FDT&E. The predominant failures were cage motor failures, dome moisture, dome cracks, elevation pot unadjustable and poor video. Many of these and other failures were due to poor design and quality control. Great differences existed among what were supposed to be identical sensor packages. Several failures originally charged to the caging mechanism and to dome moisture were deleted by the scoring conference. The caging failures due to software commands and not to the equipment itself were deleted. Four dome moisture equipment failures were deleted because a field fix all but eliminated that failure mode. The original failure was charged (KE-55) and one failure after the field fix was charged (KE-130). The fix consisted of purging the sensor package with dry nitrogen and installing a desiccant package in the breather.

TABLE 2.15 FAILURES ASSOCIATED WITH THE SENSORS WHICH WERE USED DURING THE FDT&E

Phase (Serial #)	EPR #	Failure Score Eq.	Failure Score Mis.	Description of Failure
IV (401)	KE-14	1	1	Poor video
I (T-12)	KE-34	1	1	Not responding to commands
IV (401)	KE-46	1	0	Not responding properly prior to launch
V (504)	KE-52	1	0	Sensor would not go below -55^{0} elevation
V (504)	KE-55	1	1	Dome condensation
IV (401)	KE-76	1	0	Slewing and caging difficulties
IV (401)	KE-89	1	0	Laser failed to fire due to battery
IV (401)	KE-94	1	0	Dome cracked at launch
IV (401)	KE-95	1	1	Elevation pot unadjustable
III (302)	KE-105	1	0	Set screw in azimuth drive gear fell out
III (302)	KE-105	1	0	Caging motor
IV (403)	KE-107	1	1	Autotracker failed during boresighting
IV (403)	KE-110	1	1	Caging motor overheated
IV (403)	KE-113	1	0	Elevation adjustment inoperative
IV (403)	KE-115	1	0	Dome cracked
III (304)	KE-118	1	1	Video degraded and then lost
IV (403)	KE-130	1	1	Dome condensation (after field fix)
IV (403)	KE-131	1	0	Cage pin problems during boresighting
V (501)	KE-135	1	0	Autotracker failed during boresighting
TOTALS		19	8	

The operating time, failures, MTBF and reliability for each sensor package (by phases) are listed in Table 2.16. Again, the Phase I numbers are included in the total. The total operating times are used for the MTBF estimates, as opposed to flight time which was used in the FABD analysis. The total flight time and operating time for the sensor subsystem differ from that listed for the RPV subsystem primarily for two reasons: boresight and other ground operation time are included, and Sony camera time is excluded. For consistency with the RPV subsystem, all reliability estimates are based on a mission duration of 1.88 hours and the exponential failure distribution is assumed. All of these factors contribute to the differences between the reliabilities shown in Table 2.16 and those calculated by the FABD, which were based on a total flight time of 77.7 hours and an average mission time of 1.7 hours (see Reference 3).

TABLE 2.16 RELIABILITY PARAMETERS FOR THE SENSOR SUBSYSTEM AS EXHIBITED DURING THE FDT&E. THE PHASE I VALUES ARE INCLUDED IN THE TOTALS.

	Operating Time (Hour)		Failures		MTBF (Hour)		Reliability (t = 1.88 hours)	
Phase	Flight	Total	Equipment	Mission	Equipment	Mission	Equipment	Mission
I	2.6	4.8	1	1	4.8	4.8	.68	.68
II	NOT USED IN FDT&E							
III	15.5	20.3	3	1	6.8	20.3	.76	.91
IV	40.7	65.0	12	5	5.4	13.0	.71	.86
V	17.1	28.1	3	1	9.4	28.1	.82	.93
TOTAL	75.9	118.2	19	8	6.2	14.8	.74	.88

Maintenance at the crew/organizational level was limited primarily to sensor removal and installation, boresighting, bench checks, laser battery changing/charging, purging dome with nitrogen, and repairing/replacing the dome. On-site sensor repairs by the contractor were limited to the extent above plus other minor repairs; major repairs necessitated the return of the sensor package to the factory. Table 2.17 lists the types of maintenance performed on the sensor subsystems. The average maintenance action at the crew/organizational level took 1.1 hours to perform, utilizing 2.84 man-hours.

TABLE 2.17 FDT&E MAINTENANCE ACTIONS ON THE SENSORS

	Level	Maintenance Action	Number of Actions	Total Hours Cl-Hrs	Total Hours Man-Hrs	Mean Cl-Hrs	Mean Man-Hrs	Standard Deviation Cl-Hrs	Standard Deviation Man-Hrs
SCHEDULED	Crew/Org.	Sensor removed	4	5.0	5.9	1.25	1.48	.77	1.03
		Sensor installed	12	13.4	15.7	1.12	1.31	.34	.60
		Dome purging	3	.7	.7	.23	.23	.06	.06
		Dome purging/dessicant installed	10	5.0	5.0	.50	.50	.33	.33
		Boresight operation/inspection	23	22.3	149.7	.97	6.51	.51	3.87
		Other scheduled	10	19.4	20.9	1.94	2.09	1.04	1.07
		Total (Crew/Organizational)	62	65.8	197.9	1.06	3.19	.73	3.54
	Contractor	General scheduled	6	8.7	8.7	1.45	1.45	1.41	1.41
	Both	Total scheduled	68	74.5	206.6	1.09	3.04	.81	3.44
UNSCH.	Crew/Org.	General unscheduled	18	22.1	29.6	1.23	1.64	.92	2.02
	Contractor	General unscheduled	10	16.9	27.5	1.69	2.75	1.20	3.26
	Both	Total unscheduled	28	39.0	57.1	1.39	2.04	1.03	2.53
	Crew/Org.	All maintenance	80	87.9	227.5	1.10	2.84	.77	3.32
	Contractor	All maintenance	16	25.6	36.2	1.60	2.26	1.24	2.73
	Both	All maintenance	96	113.5	263.7	1.18	2.75	.88	3.22

TABLE 2.18 MAINTAINABILITY AND AVAILABILITY INDICES FOR THE SENSOR SUBSYSTEM DURING FDT&E

	Organizational/Crew (AVUM)		Contractor (AVIM)		All Maintenance Actions	
	Scheduled	Unscheduled	Scheduled	Unscheduled	Scheduled	Unscheduled
Avg Cl-Hrs	1.06	1.23	1.45	1.69	1.09	1.39
Avg Man-Hrs	3.10	1.64	1.45	2.75	3.04	2.04
MTBM	1.91 hr	6.57 hr	19.70 hr	11.82 hr	1.74	1.23 4.22 hr
MR	3.0 man-hr/ flt hr		.47 man-hr/ flt hr		3.48 man-hr/ flt hr	
$\bar{M}$	1.1 hr		1.6 hr		1.20 hr	
A_i					.75	
A_a					.51	

During the FDT&E, laser boresight operations were difficult. Two factors were the primary contributors: (1) the hookup to the sensor control panel was made difficult by the required removal of the access panel and one of the electronics packages, and (2) the displays on the sensor control panel were difficult to read. The second difficulty was due to the fact that red Light Emitting Diode (LED) displays were used. These were difficult to read in sunlight and almost impossible to read when the laser goggles (which filters out red) were used. A liquid crystal type of display may be a better choice for the sensor control panel used for boresight operations.

Table 2.18 summarizes the maintainability and availability indices for the sensor subsystem. MTBM, Ai and Aa estimates are based on the total on-time of 118.2 hours. MR is based on a total flight time of 75.9 hours.

2.3.2 Analysis of EDT RAM Data on the Sensor Subsystem

The EDT test personnel tested all five phases of the sensor packages. A Sony camera was used occasionally to check out a new RPV platform, but is not included as part of the sensor RAM analysis. Table 2.19 lists the failures scored against the sensor subsystem during the EDT. The predominant failures were lack of control of the sensor and caging/uncaging problems. The other failures were singular incidents during the EDT.

TABLE 2.19 FAILURES ASSOCIATED WITH THE SENSORS WHICH WERE USED DURING THE EDT

Phase (Serial #)	EPR #	Failure Score Eq.	Failure Score Mis.	Description of Failure
I (T-13)	KH-8	1	.33	No azimuth control during flight
I (T-13)	KH-11	1	.33	Camera did not slew; no control
III(304)	KH-27	1	1	Video loss due to overheating
III(302)	KH-44	1	0	Stuck in caged position
I (T-6)	KH-59	1	1	Video fuzzy; filters inoperative
II (28396)	KH-66	1	1	Take up spool drive motor defective
IV (403)	KH-67	1	.5	Cage/uncage problem
IV (403)	KH-67	1	.5	Weak laser battery caused gross rangefinder errors
TOTALS		8	4.66	

Table 2.20 lists the operating time, failures, MTBF and reliability for each sensor package (by phases). Phases IV and V are combined for the following reasons: (1) EPG data did not list the operating time separately, (2) there were no failures of the Phase V sensor, and (3) these two sensor packages are virtually identical. The reliabilities listed differ from those shown in the EDT test report. The EDT reliabilities were estimated using a mission time of 1.6 hours, whereas the reliability estimates in Table 2.20 are based on 1.88 hours which is [illegible] throughout this report as the average on-time for the RPV and sens[illegible] systems.

TABLE 2.20 RELIABILITY PARAMETERS FOR THE SENSOR SUBSYSTEM AS EXHIBITED DURING THE EDT

	Operating Time (Hours)		Failures (Hours)		MTBF (Hours)		Reliability	
Phase	Flight	Total	Equip.	Mis.	Equip.	Mis.	Equip.	Mis.
I	NOT RECORDED	18.6	3	1.66	6.2	11.2	.74	.84
II		8.3	1	1	8.3	8.3	.80	.80
III		12.8	2	1	6.4	12.8	.74	.86
IV/V		7.2	2	1	3.6	7.2	.59	.77
TOTAL		46.9	8	4.66	5.9	10.1	.72	.84

The only maintenance on the sensors recorded by the EDT RAM data collectors was unscheduled sensor removals where the sensor was subsequently turned over to the contractor for repair. Contractor RAM data and scheduled maintenance at the crew/organizational level were not recorded. Table 2.21 summarizes the maintainability and availability indices for the sensor subsystem exhibited during the EDT. The numbers listed under the "All Maintenance" heading are not representative of the parameters listed because of the data voids. Because of the lack of maintenance data, these values will not be included in the data aggregation.

TABLE 2.21 MAINTAINABILITY AND AVAILABILITY INDICES FOR THE SENSOR SUBSYSTEM DURING EDT

	Organizational/ Crew (AVUM)		Contractor (AVIM)		All Maintenance Actions	
	Sched.	Unsched.	Sched.	Unsched.	Sched.	Unsched.
Avg Cl-Hrs		.3	NO DATA			.3
Avg Man-Hrs		.3				.3
MTBM		6.7 hr				6.7 hr
MR		.045				.045
$\bar{M}$		.3 hr				.3 hr
A_i						.96
A_a						.96

2.3.3 Analysis of Aggregated Sensor RAM Data

The data presented in Sections 2.3.1 and 2.3.2 were combined to determine the overall RAM indices of the sensor subsystem during all government testing. Table 2.22 summarizes the number of failures, operating time, MTBF and reliability experienced by the sensor subsystem. MTBF is based on the total operating time and all reliabilities are based on an average mission duration of 1.88 hours.

There were several pattern failures of the sensor during the government testing. The most prevalent failures were sensor caging problems (6 incidences), poor video and video loss (4 incidences), and sensor not responding properly to the given command (3 incidences). Dome condensation was also a big problem, and all but two of these failures were deleted due to a field fix which eliminated this failure mode (except for a singular occurrence after the fix). Problems with the caging primarily involved the caging motor or failure of the pin to properly set and hold the sensor in place during launch or recovery. Several caging failures were deleted because they were not hardware oriented, but were due to a software problem in the GCS. Other repeated failures were laser battery failures, dome cracking, elevation pot failures and autotracker failures.

Maintenance on the sensor at the crew/organizational level was limited primarily to sensor removal and installation, boresighting, bench checks, laser battery changing/charging, dome purging and repair/replacement of the dome. Major repairs necessitated the return of the sensor to the factory. The FDT&E RAM data collectors maintained good records of all scheduled and unscheduled maintenance actions performed at the crew/organizational level and at the contractor level (on-site). The EDT RAM data collectors only reported unscheduled sensor removals for repair by the contractor. There is insufficient information available to aggregate the data from the two tests. Therefore, the more

complete FDT&E maintenance data analysis is repeated here in Table 2.23 as being the best representative of the sensor subsystems during government testing. MTBM, A_i and A_a estimates are based on the FDT&E total on-time of 118.2 hours. MR is based on the FDT&E total flight time of 75.9 hours. The low availabilities and the high MR both may be unacceptable in the ED program.

TABLE 2.22 RELIABILITY PARAMETERS FOR THE SENSOR SUBSYSTEMS USED DURING GOVERNMENT TESTING

Sensor Phase	Operating Time (Hours) Flight	All	Failures Equip.	Mis.	MTBF (Hours) Equip.	Mis.	Reliability Equip.	Mis.
I	incomplete	23.4	4	2.66	5.8	8.8	.72	.81
II		8.3	1	1	8.3	8.3	.80	.80
III		33.1	5	2	6.6	16.5	.75	.89
IV/V		100.3	17	7	5.9	14.3	.73	.88
TOTAL		165.1	27	12.66	6.1	13.0	.73	.86

TABLE 2.23 MAINTAINABILITY AND AVAILABILITY INDICES FOR THE SENSOR SUBSYSTEM DURING FDT&E. THESE VALUES ARE THE BEST AVAILABLE REPRESENTATIVES OF THE MAINTAINABILITY AND AVAILABILITY INDICES FOR THE SENSOR SUBSYSTEM DURING GOVERNMENT TESTING.

	Organizational/Crew (AVUM) Sched.	Unsched.	Contractor Sched.	Unsched.	All Maintenance Actions Sched.	Unsched.
Avg Cl-Hrs	1.0	1.2	1.4	1.7	1.1	1.4
Avg Man-Hrs	3.2	1.6	1.4	2.7	3.0	2.0
MTBM (hours)	1.9	6.6	19.7	11.8	1.7 | 1.2	4.2
MR	3.0 man-hr/flt hr		.5 man-hr/flt hr		3.5 man-hr/flt hr	
$\bar{M}$	1.1 hours		1.6 hours		1.2 hours	
A_i					.75	
A_a					.51	

2.4 RAM Characteristics of the Launcher Subsystem

2.4.1 Analysis of FDT&E RAM Data on the Launcher Subsystem

The FDT&E test team used launcher number 9754 throughout the FDT&E. There were very few failures of this launcher during the test. Table 2.24 lists the failures. The predominant failure was the spring pin on the starter motor drive shaft shearing when engine start was commanded. It was thought that this failure was due to the large number of engine starts causing the spring pin to wear out. This was only partially true. It was discovered on the last failure (KE-119) that the brass bushing through which the pin is placed was wearing in an oblong manner allowing excessive free play on the drive shaft. This was causing the frequent failures of the spring pin. The brass bushing was rotated 90 degrees and redrilled to allow installation of the spring pin. This type of failure was not repeated again. Even with this fix, however, it can be expected that the spring pin would fail again after repeated launches or when the bushing again wears out.

TABLE 2.24 FAILURES ASSOCIATED WITH THE LAUNCHER WHICH WAS USED DURING THE FDT&E

		Failure Score		
	EPR #	Eq.	Mis.	Description of Failure
1	KE-16	1	0	Crack in right-hand shuttle FOD guard
2	KE-27	1	0	Regulated 24 VDC power supply cycling intermittently
3	KE-42	1	1	Spring pin in starter motor
4	KE-84	1	1	Pressure transducer failed
5	KE-102	1	0	Spring pin in starter motor
6	KE-119	1	1	Spring pin in starter motor
	TOTALS	6	3	98.6 operating hours, 50 launch attempts, 47 successful launches

The launcher was operated (power-on) for 98.6 hours. The 107 hours reported in the FDT&E report is incorrect due to addition errors. There were 50 launch attempts, including an EPG launcn and dry runs, and 47 successful launches. There were actually 59 attempts to launch, but those mission aborts were due to problems not related to the launcher and were not charged as launch attempts. The on-times for those aborts were included in the determination of the average on-time, however. The reliability estimations using the exponential failure distribution are based on the average of all the launcher on-times of 1.5 hours. Based on the above information, the following reliability parameters were estimated:

	Equipment	Mission
MTBF	$\frac{98.6}{6} = 16.43$ hr	$\frac{98.6}{3} = 32.87$ hr
Reliability	.91	.95
Probability of Successful Launch	NA	$\frac{47}{50} = .94$
MLBF	$\frac{47}{6} = 7.8$ launches	$\frac{47}{3} = 15.6$ launches

Probability of successful launch is defined as the number of successful launches divided by the number of attempted launches. This excludes attempted launches scrubbed due to failures of subsystems other than the launcher. Mean-launches-between-failures (MLBF) is defined as the number of successful launches divided by the number of failures.

With one exception, all scheduled maintenance at the crew/organizational level were pre-launch preventative maintenance checks. The only other scheduled maintenance action was the installation of a head guard behind the starter motor. There were no scheduled maintenance actions performed by the contractor. The unscheduled maintenance actions at the crew/organizational level and the contractor level correspond with the failures listed in Table 2.24, along with some unscheduled calibrations and checks. No unusual difficulties were experienced in maintaining the launcher subsystem. Table 2.25 summarizes the maintainability and availability indices for the launcher used in FDT&E. A new figure of merit is included, mean-launches-between-maintenance (MLBM).

2.4.2 Analysis of EDT RAM Data on the Launcher Subsystem

The EDT test team used launcher number 9753 throughout the EDT. This launcher had also been used by the contractor during their testing. No RAM data or operating time was collected by the contractor. Therefore, for this analysis, operating time and number of launches on this launcher is assumed to be zero at the start of the EDT. However, the EDT RAM data collectors did not record the operating times of the launcher; therefore, only probability of successful launch can be calculated.

Table 2.26 lists the failures of the launcher during the EDT. The shock mount failure was not experienced during the FDT&E, but was experienced three times during the EDT. The shock mounts have a limited lifetime and were replaced as a matter or routine. The one failure listed was chargeable because the shock mounts had recently been replaced but had prematurely deteriorated to the point where they were not usable. The shock mounts are usually good for a total of about three or four launches. One spring pin failure was reported. (There were three during the FDT&E.) The other two failures were isolated incidents.

TABLE 2.25 MAINTAINABILITY AND AVAILABILITY INDICES FOR THE LAUNCHER SUBSYSTEM (# 9754) USED DURING FDT&E

	Organizational/Crew (AVUM)		Contractor (AVIM)		All Maintenance Time	
	Sched.	Unsched.	Sched.	Unsched.	Sched.	Unsched.
Avg. Cl-Hrs	.41	1.56	None	1.45	.41	1.52
Avg. Man-Hrs	.82	3.61		1.45	.82	2.80
MTBM (hours)	1.67	9.86		16.40	1.67	1.31 6.16
MLBM (launches)	.80	4.70		7.83	.80	.63 2.94
MR	.86 man-hr/op hr		.09 man-hr/op hr		.95 man-hr/op hr	
$\underline{MR}$	1.80 man-hr/launch		.18 man-hr/launch		1.98 man-hr/launch	
$\overline{M}$	.58 hours		1.45 hours		.65 hours	
A_1					.69	
A_2					.59	

TABLE 2.26 FAILURES ASSOCIATED WITH THE LAUNCHER USED DURING EDT

	EPR #	Failure Score Equipment	Mission	Description of Failure
1	KH-17	1	1	high pressure hose overstressed due to overpressurizing
2	KH-28	1	0	rear shock mount
3	KH-45	1	0	spring pin in starter motor
4	KH-47	1	0	launcher control box
TOTALS		4	1	36 successful launches, 1 scrub due to launcher failure

Since there was no operating time recorded on the EDT launcher, no MTBF or reliability estimates can be made. Point estimates for the probability of successful launch and mean-launch-between-failure (MLBF), can be computed. These values as exhibited during the EDT are as follows (see Section 2.4.1 for definitions):

	Equipment	Mission
Probability of successful launch	NA	$\frac{36}{37} = .97$
MLBF	$\frac{36}{4} = 9.0$	$\frac{36}{1} = 36.0$

The EDT RAM data collectors recorded only the scheduled and unscheduled maintenance actions performed at the crew/organizational level. No contractor data was recorded. Scheduled maintenance consisted of pre/post flight checks. Unscheduled maintenance consisted primarily of repair/replacement actions required due to the failures discussed earlier in this section. Table 2.27 summarizes the maintainability indices for the launcher used in EDT. MLBM is defined as the number of launches divided by the number of maintenance actions. MR is defined as the number of man-hours of maintenance required per launch. These two definitions differ from those used previously where the MTBM and MR were based on operating or flight time. The difference is necessitated because of the failure of the EDT RAM data collectors to record the launcher operating hours, which also precludes the calculation of availability indices for the EDT launcher.

2.4.3 Analysis of Aggregated Launcher RAM Data

The data presented in Sections 2.4.1 and 2.4.2 were combined to the extent possible to determine the overall RAM characteristics of the launcher subsystem during all government testing. Table 2.28 summarizes the aggregated reliability data. The aggregated data are not as complete as desired due to the failure of the EDT RAM data collectors to record the operating time on the launcher. The predominant equipment

TABLE 2.27 MAINTAINABILITY INDICES FOR THE LAUNCHER SUBSYSTEM (# 9753) USED DURING EDT

	Organizational/Crew(AVUM)		Contractor (AVIM)		All Maintenance Time	
	Scheduled	Unscheduled	Scheduled	Unscheduled	Scheduled	Unscheduled
Avg Cl-Hrs	.33	.65	None	None	.33	.65
Avg Man-Hrs	.79	1.03			.79	1.03
MLBM (launches)	1.00	4.50			1.00	.82 4.50
MR	1.02 man-hrs/ launch				1.02 man-hrs/ launch	
$\overline{M}$	.39 hours				.39 hours	
A_i					cannot be calculated	
A_a					cannot be calculated	

failure recorded was the shearing of a spring pin on the starter motor drive shaft (4 incidents). This failure was partially due to the large number of engine starts causing the spring pin to wear out. The second most common problem (although only one failure was charged) was the rapid wearout of the shock mounts. The shock mounts are usually good for three to four launches and then must be replaced. The one failure was charged when one mount failed prematurely. Another problem area was the failure to maintain the proper launch pressure due to either a pressure transducer failure or launcher control box failure. Direct replacement and/or calibration usually alleviated the problem. On the whole, the reliability estimates for the launcher presented in Table 2.28 are better than those for the other subsystems which have been presented so far.

TABLE 2.28 LAUNCHER RELIABILITY DATA AND ANALYSIS FOR ALL GOVERNMENT TESTING

	FDT&E	EDT	AGGREGATE
Equipment Failures	6	4	10
Mission Failures	3	1	4
Operating Hours	98.6	Not Recorded	
Launch Attempts*	50	37	87
Successful Launches	47	36	83
MTBF (Equipment), hours	16.43		
MTBF (Mission), hours	32.87		
Reliability (Equipment)	.91		
Reliability (Mission)	.95		
Probability of Successful Launch	.94	.97	.95
MLBF (Equipment), launches	7.8	9.0	8.30
MLBF (Mission), launches	15.6	36.00	20.75

*Launch attempts scrubbed due to failures not related to a launcher malfunction are not included.

Most scheduled maintenance at the crew/organizational level consisted of pre/post launch preventative maintenance. There were no scheduled maintenance actions performed by the contractor. Unscheduled maintenance consisted primarily of repair/replacement actions required due to the failures. No unusual difficulties were experienced in maintaining the launcher subsystems. Table 2.29 summarizes the maintainability and availability indices for the two launchers used during government testing. MTBM, MR (man-hours per operating hour), A_i and A_a estimates are based only on FDT&E data because the operating time was not collected on the EDT launcher. The average unscheduled clock hours required for maintenance would not meet the ED requirements.

TABLE 2.29 MAINTAINABILITY AND AVAILABILITY INDICES FOR THE LAUNCHER SUBSYSTEMS USED DURING GOVERNMENT TESTING

	Organizational/Crew (AVUM)		Contractor (AVIM)		All Maintenance Time	
	Scheduled	Unscheduled	Scheduled	Unscheduled	Scheduled	Unscheduled
Avg Clk-Hrs	.38	1.16		1.45	.38	1.20
Avg Man-Hrs	.81	2.46		1.45	.81	2.20
MTBM	1.67 hr	99.86 hr		16.40 hr	1.67	1.31 6.16 hr
MLBM, launches	.87	4.61		13.83	.87	.70 3.46
MR	1.80 man-hr/op hr		.09 man-hr/op hr		.95 man-hr/op hr	
$\underline{MR}$	1.46 man-hr/launch		.11 man-hr/launch		1.57 man-hr/launch	
$\overline{M}$	.5 hr		1.45 hour		.55 hr	
A_i					.69	
A_a					.59	

2.5 RAM Characteristics of the Retrieval Subsystem

One retrieval subsystem was used by both test teams. There were also very few failures and maintenance actions on the retrieval unit. For these reasons, it is best to combine all RAM data on this subsystem collected during government testing and present the combined analysis. Table 2.30 summarizes the aggregated reliability data. All attempts at retrieval were successful. None of the equipment failures resulted in damage to the RPV or in mission delay, thus no mission failures were charged and the MRBF for mission failures cannot be estimated. However, RPV damage due to recovery was common but cannot be considered a failure of the retrieval system to recover the aircraft. The predominant damages to the RPV incurred during recovery were: torn wing tips, torn and dented nose caps, and transmitting antenna support broken. These damages are considered minor and easily replaced/repaired. One retrieval early in the testing resulted in extensive structure and sensor damage. This was due to a failure of the payload protector, not the retrieval unit. The retrieval system works very well from the standpoint of RAM and cannot be held accountable for the fragility and shortcomings of the airframe. The retrieval unit does have some deficiencies in the areas of human factors design and the resultant excessive set-up time. This and other problems are discussed in the AMSAA Independent Evaluation Report on the AQUILA system.

TABLE 2.30 RETRIEVAL RELIABILITY DATA AND ANALYSIS FOR ALL GOVERNMENT TESTING

	FDT&E	EDT	AGGREGATE
Equipment Failures	3	0	3
Mission Failures	0	0	0
Retrieval Attempts	44	33	77
Retrieval Successes	44	33	77
Probability of Successful Retrieval	1.0	1.0	1.0
MRBF (Equipment), retrievals	14.7	No failures	25.7

Table 2.31 lists the three equipment failures during the FDT&E. It is not known what effect would have resulted if the oil leak had not been discovered and repaired. The retainer clip failures on the hydraulic energy absorbers occurred after a design modification was implemented on 17 August 1977. The cause for the retainer clips springing open has not been determined. The design change was made because the previous design had been breaking in high wind conditions.

TABLE 2.31 RETRIEVAL SUBSYSTEM EQUIPMENT FAILURES. ALL OCCURRED DURING THE FDT&E

	EPR #	Description of Failure
1	KE-12	Oil seal in energy absorber leaking oil
2	KE-91	Retainer clip on energy absorber sprung
3	KE-116	Retainer clip on energy absorber sprung

Most scheduled maintenance at the crew/organizational level consisted of pre/post flight preventative maintenance. The one exception was a time change item where the vertical net support line was changed. Site set-up time is not included. There was no scheduled contractor maintenance during either the FDT&E or the EDT. Unscheduled maintenance was required to repair the failures listed in Table 2.31. The contractor also adjusted a shock absorber and trimmed the vertical net rope once during the FDT&E. There were no unscheduled maintenance actions at either level of repair during the EDT. Table 2.32 presents a summary of the maintainability and availability indices for the retrieval subsystem as exhibited during all government testing. The availabilities were estimated using the following formulas:

$$A_i = \frac{MTBM}{MTBF + MTTR}, \quad A_a = \frac{MTBM}{MTBM + \bar{M}},$$

where $MTBF = \frac{128 \text{ days}}{3 \text{ failures}} = 42.67$ days

$$MTTR = .6 \text{ hrs} \times \frac{1 \text{ day}}{24 \text{ hours}} = .025 \text{ days}$$

$$MTBM = \frac{128 \text{ days}}{99 \text{ maintenance actions}} = 1.29 \text{ days}$$

$$\bar{M} = .46 \text{ hours} \times \frac{1 \text{ day}}{24 \text{ hours}} = .02 \text{ days}$$

The test length, 128 days, is total test time starting at the beginning of FDT&E on 14 July 1977 and going through the last day of the EDT test on 18 November 1977. This is the most appropriate method for estimating the retrieval unit's availabilities since operating time is not a viable entity on this subsystem.

2.6 RAM Characteristics of the AQUILA RPV System

2.6.1 Reliability.

The reliability of the entire RPV system can be estimated by considering the system as a series of five independent subsystems with no

TABLE 2.32 MAINTAINABILITY AND AVAILABILITY INDICES FOR THE RETRIEVAL SUBSYSTEM USED DURING GOVERNMENT TESTING

	Organizational/Crew (AVUM)		Contractor (AVIM)		All Maintenance Time	
	Scheduled	Unscheduled	Scheduled	Unscheduled	Scheduled	Unscheduled
Avg Cl-Hrs	.45 hr	.4	0	.8	.45	.60
Avg Man-Hrs	1.00	.8	0	.8	1.00	.80
MRBM	.81 ret	38.5 ret	—	38.5 ret	.81	.78 19.25 ret
MR	.79 man-hr/ret		.02 man-hr/ret		.81 man-hr/ret	
$\overline{M}$	.45 hr		.80 hr		.46 hr	
A_i					.999	
A_a					.98	

redundancies as follows:

— LAUNCHER — GCS — RPV — SENSOR — RETRIEVAL —

Using this model, the system reliability estimate is calculated by multiplying the reliabilities of the individual subsystems. Even though the individual subsystem reliabilities were estimated using different time bases, the reliabilities for the subsystems as expressed in the previous sections may be directly multiplied due to their independence. Table 2.33 summarizes the individual subsystem reliabilities and the overall system reliabilities. Figures given in parentheses include the quality control failures whereas the other numbers do not.

TABLE 2.33 AQUILA RPV SYSTEM RELIABILITY ESTIMATES

SUBSYSTEM	RELIABILITY PARAMETER	EQUIPMENT RELIABILITY		MISSION RELIABILITY	
Launcher	Prob (Successful Launch)	.95		.95	
GCS	R(t = 3.2 hrs)	.76		.92	
RPV	R(t - 1.88 hrs)	.47	(.39)	.74	(.73)
Sensor	R(t = 1.88 hrs)	.73		.86	
Retrieval	Prob (Successful Retrieval)	1.0		1.0	
SYSTEM	Product of Entries	.25	(.21)	.56	(.55)

The two weakest links in the system are the RPV subsystem and the sensor subsystem. These subsystems in the upcoming ED RPV system must meet reliability requirements which are higher than those exhibited during the Advanced Development Program. Ground Control Station reliability must also be improved in order to meet the ED requirements. Some improvement in RAM will also be necessary on the launcher and retrieval subsystems in order to meet the ED RPV system requirements. As expected, the system's equipment and mission reliabilities must be considered unsatisfactory from the standpoint of the requirements for the ED system.

There were two failures scored against the auxiliary support system which are not included in the reliability figures in Table 2.33. They were: (1) leaks in the fuel filler pumps used by both test teams and (2) a phantom failure of the sensor control panel used during boresight operations to respond properly. In the second failure the unit was bypassed and could not be repeated when tested later. These are presented for information.

Table 2.34 presents a summary of all the system failures experienced during government testing. The operating time, launches or recoveries of the individual subsystems which is used to estimate the mean time (launches or recoveries) between failure is also presented. Values including the quality control failures are in parentheses.

TABLE 2.34 SUMMARY OF SYSTEM FAILURES AND MTBF's. SYSTEM MTBF IS BASED ON THE GCS OPERATING TIME. LAUNCHER AND RETRIEVAL UNIT MEAN LAUNCHES/RECOVERIES BETWEEN FAILURE ARE BASED ON LAUNCHES AND RECOVERIES, RESPECTIVELY.

	Failures		Operating	MTBF, Hours	
SUBSYSTEM	Equipment	Mission	Time	Equipment	Mission
Launcher	10	4	83 launches	8.3	20.7
GCS	29	9.66	351.5 hours	12.1	36.4
RPV	59(73)	24(25)	147.8 hours	2.5(2.0)	6.2(5.9)
Sensor	27	12.66	165.1 hours	6.1	13.0
Retrieval Unit	3	0	77 retrievals	25.7	—
Other	2	0	—	—	—
TOTALS	130 (144)	50.33(51.33)	351.5 hours	2.7 (2.4)	7.0 (6.8)

2.6.2 Reliability Growth.

Reliability growth projections using the results of AQUILA testing as a starting point and the Engineering Development Program requirements stated in the ROC as the end point can be made. The ROC gives two types of system reliability requirements, both of which are based on the mission failure definition. These are a system flight reliability (sensor excluded of .91 and a system mission reliability (given successful launch and recovery) of .82, both for a three hour mission. Using the exponential failure distribution, the flight MTBF requirement is 31.8 hours and the mission MTBF requirement is 15.1 hours. Basing the MTBF on the GCS operating hours and using the mission failure definitions in the ED ROC, the MTBF estimates for the AQUILA program were 9.1 hours flight MTBF and 7.4 hours mission MTBF (government testing only).

To develop the reliability growth curves, the total test hours to be accumulated through the end of DT/OT II must be assumed. There were 351.5 hours accumulated during the FDT&E/EDT. During the Engineering Development Program, approximately twice that amount of time should be accumulated on testing by the contractor and government; 750 hours will be assumed. This gives a test total over all RPV system development of about 1100 hours. This figure will be used as the point in time at which the ED ROC requirements must be met.

The AQUILA system as tested by the government was essentially a fixed configuration. There were few test/fix situations where a major failure mode was eliminated by a change in the hardware. Two exceptions were a fix to eliminate the dome condensation which formed during some flights and an engineering change to the spring retainer clip on the retrieval unit. Mission failures due to dome condensation were deleted at the failure scoring conference with the exception of the initial failure and one after the fix. Thus, the failure mode was not eliminated entirely. A small amount of growth was realized through this change especially in the sensor subsystem. However, the overall system's mission MTBF did not change enough to significantly affect the shape of the reliability growth curves. There were no mission failures due to the retainer clip. Therefore, it can be stated that there was essentially no reliability growth during the period of government testing.

Since there was essentially no growth, the average MTBF over the entire test period can be considered representative of the system at both the beginning and the end of test. The starting point of the curve should be placed as close to the beginning of the test period as possible. Historically, the MTBF of systems has been examined at 20 hour intervals. A good starting point for the curve is chosen as the midpoint of the first 20 hour interval. Thus, the reliability growth curves start at 10 hours and are projected out to 1100 hours.

Figures 2.1 and 2.2 show the reliability growth curves for the RPV system flight reliability and for the RPV system mission reliability, respectively. The curves also show the incremental MTBF exhibited over each 20 hour interval, the average MTBF exhibited over the entire test period and the cumulative MTBF of the system as it approached the final test average. No incremental MTBF is shown for the 260 to 280 hour interval because there were no failures during this interval. The equation for the Weibull reliability growth curve is

$$\text{MTBF} = \frac{1}{\lambda \beta t^{\beta - 1}} .$$

Using the two end points of the curve to give two equations with two unknowns, the two parameters, λ and β, can be estimated. The most important of these is β. A rule of thumb for reliability growth methodology is that a β which is less than .5 indicates a program which would have to work very aggressively to meet the reliability goal. When β increases above .5, the system reliability goal becomes more attainable. (A β of 1 indicates that no growth is necessary.) The β's shown for the two reliability growth curves in Figures 2.1 and 2.2 are both above .5, indicating that the goals set forth in the ROC are not unreasonable.

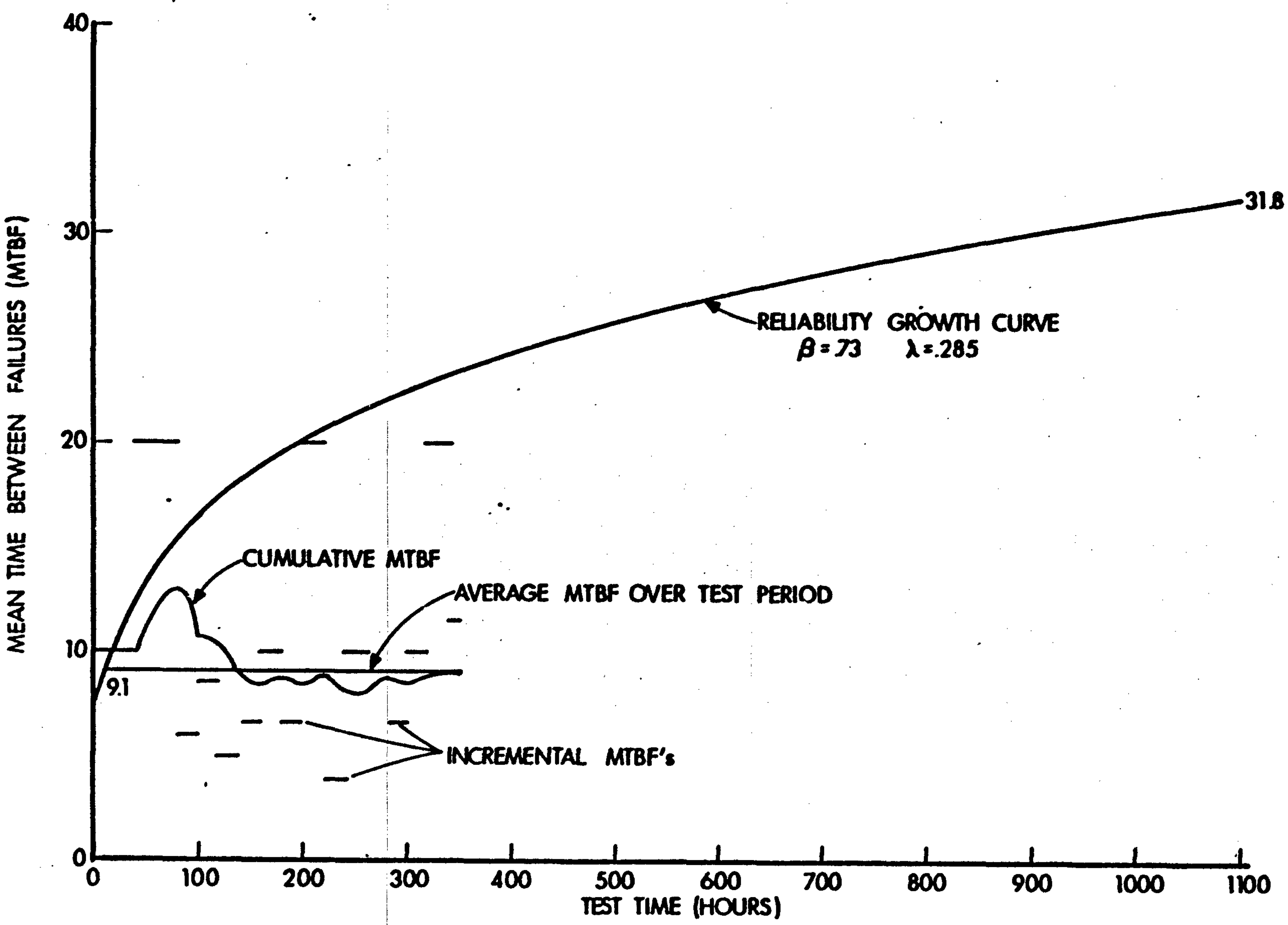


Figure 2. 1 Reliability Growth Curve for RPV System Flight Reliability (Sensor Excluded).

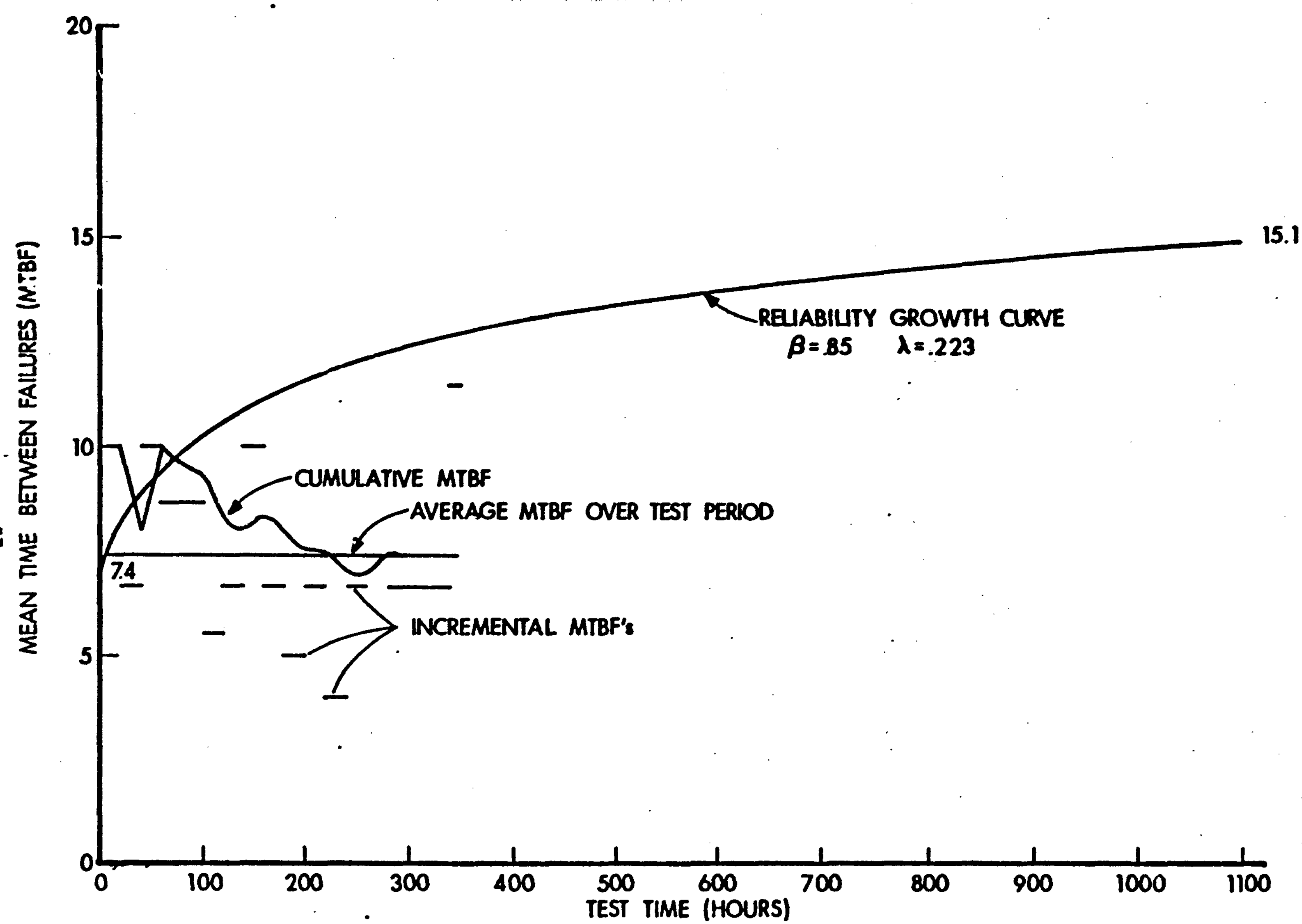


Figure 2.2 Reliability Growth Curve for RPV System Mission Reliability (Given Successful Launch and Recovery)

2.6.3 Maintainability and Availability

The overall maintainability of the RPV system can be considered unsatisfactory for the reasons stated in the following sentences. Pre-flight checks on all subsystems were lengthy and required highly skilled maintenance personnel to perform them. The manuals provided by the contractor contained no scheduled preventative maintenance guides for the organizational category. Tools and repair parts were inadequate. Quality control of in-plant repairs and overhaul was poor. All of these factors contributed to making some portions of maintenance time-consuming and cumbersome.

The RPV subsystem was the most difficult to maintain. The number of man-hours spent performing both scheduled and unscheduled maintenance per flight hour on the RPV subsystem constituted more than half of the maintenance man-hours expended on the system during government testing. RPV subsystem maintainability must be improved to meet the ED system requirements, especially in the time spent on pre-flight checks (about 4 hours).

Table 2.35 presents a summary of the maintainability and availability indices for the AQUILA RPV system. The total system MTBM is based on a system operating time of 351.5 hours, which is the same as the GCS operating time. This subsystem was the longest operating of all subsystems, and the majority of operating times of the other subsystems is contained within the GCS operating time. System MR is based on the total RPV flight time of 123.7 flight hours. $\overline{M}_{unsch}$ (mean maintenance time-unscheduled) is the same as MTTR (mean-time-to-repair). The $\overline{M}_{unsch}$ at both the AVUM and AVIM levels of repair exceeds the ED requirement by 95.2 percent and 69 percent, respectively. The number of maintenance man-hours required to obtain one hour of flight may be considered excessive in view of ED system requirements. Actual clock hours of maintenance per flight hour (7.4 hours) may also be excessive. In order to meet the requirements for the ED program, many improvements must be made, particularly in the problem areas cited previously in this section and particularly in the area of designing for maintainability into the system.

The system availability estimates are also based on the operating time of the GCS. (The individual subsystem availabilities in the table are based on their own subsystem operating time.) The system availabilities are estimated using the following formulas:

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

$$A_a = \frac{MTBF}{MTBM + \overline{M}}$$

The AQUILA system availability estimates are:

Inherent Availbility (A_I) .59

Achieved Availability (A_a) .28

The inherent availability requirements for the follow-on ED system as determined from the reliability and maintainability requirements stated in the ROC can only be determined at the two maintenance levels, AVUM and AVIM, rather than a value for the overall system as is desired. An achieved availability requirement cannot be determined from the reliability and maintainability requirements as stated in the ROC. Thus, no comparison of where the system is now to where the follow-on ED system must be at IOC can be made. These low availability estimates still must be considered to be less than desirable for a fieldable RPV system in its intended operational environment.

TABLE 2.35 MAINTAINABILITY AND AVAILABILITY INDICES FOR THE AQUILA RPV SYSTEM TECHNOLOGY DEMONSTRATOR AS EXHIBITED DURING GOVERNMENT TESTING

	System	GCS	RPV	Sensor	Launcher	Retrieval	System
O/C Level (AVUM)	$\overline{M}_{SCHED}$	.59 hr	1.7 hr	1.1 hr	.38 hr	.45 hr	.97 hr
	$\overline{M}_{UNSCH}$	.54 hr	1.0 hr	1.2 hr	1.16 hr	.40 hr	.98 hr
	$\overline{M}_{BOTH}$	.58 hr	1.5 hr	1.1 hr	.50 hr	.45 hr	.97 hr
Contractor (AVIM)	$\overline{M}_{SCHED}$	2.50 hr	2.6 hr	1.4 hr	0.00 hr	0.00 hr	2.09 hr
	$\overline{M}_{UNSCH}$	1.63 hr	3.5 hr	1.7 hr	1.45 hr	.80 hr	3.38 hr
	$\overline{M}_{BOTH}$	1.79 hr	3.3 hr	1.6 hr	1.45 hr	.80 hr	3.11 hr
All Maint.	$\overline{M}_{SCHED}$	.67 hr	1.7 hr	1.1 hr	.38 hr	.45 hr	1.19 hr
	$\overline{M}_{UNSCH}$	.96 hr	1.6 hr	1.4 hr	1.20 hr	.60 hr	1.68 hr
	$\overline{M}_{BOTH}$	.77 hr	1.7 hr	1.2 hr	.55 hr	.46 hr	1.32 hr
	MR AVUM	.31 mn-hr/ op hr	5.9 mn-hr/ flt hr	3.0 mn-hr/ flt hr	1.46 mn-hr/ launch	.79 mn-hr/ ret	10.88 mn-hr/ flt hr
	MR AVIM	.17	1.5	.5	.11		3.57
	MR BOTH	.48	7.4	3.5	1.57		14.45
	A_i	.79	.50	.75	.69	.999	.59
	A_a	.71	.25	.51	.59	.98	.28
	$MTBM_{SCHED}$	5.17 hr	.78 hr	1.7 hr	.87 launch	.81 ret	.69 hr
	$MTBM_{UNSCH}$	9.50 hr	1.87 hr	4.2 hr	3.46 launch	19.25 ret	1.9 hr
	$MTBM_{BOTH}$	3.35 hr	.55 hr	1.2 hr	.70 launch	.78 ret	.51 hr

ABBREVIATIONS

A_a	- Achieved Availability
A_i	- Inherent Availability
AMSAA	- Army Materiel Systems Analysis Activity
AVIM	- Aviation Intermediate Maintenance
AVUM	- Aviation Unit Maintenance
BOC	- Best Operational Capability
Cl-hrs	- Clock-hours
DARCOM	- Development and Readiness Command
DTP	- Detailed Test Plan
ED	- Engineering Development (also FSED, see below)
EDT (also EDT-G)	- Engineering Design Test
EPG	- Electronics Proving Ground
EPR	- Equipment Performance Report
Eq	- Equipment (as in Equipment Reliability)
FAALS	- Field Artillery Acoustic Location System
FABD	- Field Artillery Board
FCEP	- Flight Control Electronics Package
FDT&E	- Force Development Test and Experimentation
FEBA	- Forward Edge of Battle Area
FIREFINDER	- Mortar/Artillery Locating Radar (MALOR) System (AN-TPQ-36 and AN-TPQ-37)
flt	- Flight
FO	- Forward Observer
FSED	- Full Scale Engineering Development
g	- Earth gravity equivalent
GCS	- Ground Control Station
GSR	- Ground Surveillance Radar
Hr	- Hour(s)
IOC	- Initial Operational Capability
KPH	- Kilometers Per Hour
KW	- Kilowatt

LCD	- Liquid Crystal Display
LED	- Light Emitting Diode
LMSC	- Lockheed Missile and Space Corporation
LOA	- Letter of Agreement
$\bar{M}$	- Mean Maintenance Time
Man-hr	- Man-hours(s)
MAV	- Minimum Acceptable Value
MAXTTR	- Maximum Time to Repair
Mis	- Mission (as in Mission Reliability)
MLBF	- Mean Launches Between Failure
MLBM	- Mean Launches Between Maintenance
mm	- millimeters
MR	- Maintenance Ratio
MRBF	- Mean Retrievals Between Failure
MRBM	- Mean Retrievals Between Maintenance
MTBF	- Mean Time Between Failure
MTBM	- Mean Time Between Maintenance
MTTR	- Mean Time to Repair
MUBF	- Mean Units Between Failure (e.g., Time, Launches, Retrievals)
OV-1	- Designation for Mohawk Aircraft
RAM	- Reliability, Availability and Maintainability
REMBASS	- Remotely Monitored Battlefield Sensor System
Ret	- Retrievals
ROC	- Required Operational Capaoility
RPAODS	- Remotely Piloted Aerial Observation and Designation System
RPM	- Rotations per Minute
RPV	- Remotely Piloted Vehicle
RPV-STD	- Remotely Piloted Vehicle - System Technology Demonstrator
R/TA	- Reconnaissance/Target Acquisition
SCT	- Suitcase Tester
SOTAS	- Stand-off Target Acquisition System
STD	- System Technology Demonstrator
TARS-75	- Target Acquisition Reconnaissance Study - 75
TDP	- Test Design Plan

TRADOC	- Training and Doctrine Command
TV	- Television
USACDC	- United States Army Combat Development Command
USAEPG	- United States Army Electronics Proving Ground
USAFABD	- United States Army Field Artillery Board

REFERENCES

1. Letter of Agreement (LOA) for the Investigation of a Remotely Piloted Vehicle (RPV) Development Program, Combined Arms Center, ATCA-CCM-S, 26 April 1977.

2. Final Report - Engineering Design Test-Government (EDT-G) of Remotely Piloted Vehicle - System Technology Demonstrator, RPV-STD, Mr. Scott Morris, U S Army Electronics Proving Ground, February 1978.

3. Final Report - Force Development Test and Experimentation of a Remotely Piloted Vehicle (RPV) System, CPT G. Gordon Tillery, et al, U S Army Field Artillery Board, 6 January 1978.

4. (C) Draft Required Operational Capability (ROC) for a Remotely Piloted Vehicle (RPV) Target Acquisition/Designation Reconnaissance System (TADRS) (U), Combined Arms Center, TRADOC Systems Manager - Remotely Piloted Vehicles (TSM-RPV), Fort Sill, Oklahoma, 22 December 1977.

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